DRAFT NATIONAL PROGRAM PLAN FOR BIOMASS ETHANOL

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1. PROGRAM GOALS, VISION AND MISSION

Program Vision

To realize the large-scale use of environmentally-sound, cost-competitive, biomass-based ethanol fuel in the transportation sector, for the benefit of the Nation.

Program Mission

To research, develop, demonstrate, and facilitate the commercialization of biomass-based, environmentally-sound, cost-competitive U.S. technologies, and to displace petroleum use for transportation, leading to the establishment of a major biomass ethanol industry. To exploit near-term niche markets by using low-cost biomass-derived wastes and residues, while positioning the biomass ethanol industry for the long-term bulk fuel markets based on energy crops.

Strategies to meet these ends include: the research and development of integrated biofuels systems; the creation of strategic partnerships with U.S. industry and other stakeholders; and improving the operations of the program through well-defined metrics, communication, and coordination with stakeholders and customers.

The Department of Energy (DOE), Office of Fuels Development (OFD)'s Biofuels Program is conducting research, development, demonstration, and commercialization activities to encourage the creation of a biomass ethanol industry, and the use of ethanol as a biofuel or fuel additive for transportation. The Ethanol Program has established a set of ethanol production cost goals and strategic objectives that drive the research and technology development activities, and are related to the performance measures listed below (see Box) for biomass-to-ethanol conversion technology activities.

TECHNICAL GOALS THAT DRIVE BIOMASS-TO-ETHANOL CONVERSION TECHNOLOGY ACTIVITIES

Program Goals

- In collaboration with industry partners, commercial demonstration scale production of ethanol from low-cost biomass-derived wastes and residues by year 2000 at $1.13/gallon.
- In collaboration with industry partners, commercial demonstration scale production of ethanol from switchgrass/wastes by 2005 at $0.95/gallon.
- To produce ethanol from perennial biomass crops and low value feedstocks by 2010 at $0.72 per gallon

Strategic Objectives to Achieve Program Goals

- Partner with industry for near term demonstration and deployment in niche markets
- Conduct R&D in advanced technology areas to ensure potential cost reductions for next generation technologies

The year 2000 goal is to demonstrate, in collaboration with industry, technologies that can produce ethanol from low cost cellulosic waste materials at a cost of $1.13 per gallon (1997 dollars), assuming that we have access to a waste feedstock that costs no more than $15 per dry ton. This goal applies to greenfield facilities. However, most of the projects presently being considered are retrofits of existing facilities or add-on to the existing biomass power facilities. These options have the potential to significantly lower the capital investment and ethanol production cost in the range of 70 to 90 cents per gallon.

Partnerships have been established throughout the country that are poised to build these demonstration facilities. For example, Arkenol, Inc. is pursuing a rice-straw-to-ethanol facility in Sacramento, CA. BC International plans to break ground in 1998 in Jennings, LA to construct a facility that will convert sugar cane bagasse to ethanol. Masada Resources Group is planning a municipal solid waste-to-ethanol facility in Orange County, New York. Our commercial demonstrations are highly leveraged industry driven partnerships. Each of these facilities is being financed with an 80 percent or higher private sector investment and a 20 percent or less DOE cost-share. These partnerships are instrumental in achieving our programmatic goals. They will directly impact the efficiency and cost of the feedstock production and conversion technologies necessary to ensure the long-term viability of bioethanol as a transportation fuel.

For feedstock development, technical goals that drive the program's R&D initiatives in the near-, mid- and long-term are described below (see Box).

BIOMASS FEEDSTOCK DEVELOPMENT PROGRAM

Program Goals

- Commercial-scale supply of perennial crop biomass to an ethanol plant at $37/dry ton by 2005.
- Viable biomass production, handling and delivery systems on 1 percent of cropland (3 million acres) at $37/dry ton by year 2015 with environmentally acceptability.
- Viable biomass production, handling and delivery systems on 4 percent of U.S. cropland (12 million acres) at $37/dry ton by 2025 with environmental acceptability.

Strategic Objectives to Achieve Program Goals

- Focus on two model species, one woody and one herbaceous crop.
- Create regional feedstock development centers or consortia for 4 regions (North Central, South, Southeast, and Northeast).
- Facilitate partnering between farmers and potential commercial ventures for producing ethanol from cellulosic materials.

This National Program Plan for Biomass Ethanol documents planned multi-year activities, responsible organizations or individuals, and resources needed by the Biofuels Program to accomplish its goals. The document is intended to facilitate program management and internal communication efforts within the Office of Fuels Development (OFD), Office of Transportation

Technologies (OTT), by outlining the global approach of the Biofuels Program for the near-term, mid-term, and long-term goals.

The Office of Fuels Development sponsors core technology development activities at Oak Ridge National Laboratory (ORNL) for biomass feedstock development, and at the National Renewable Energy Laboratory (NREL) for biomass conversion to ethanol. This is being done in a close collaboration with industry partners, Federal and State Government organizations, academic institutions, and other stakeholders (including vehicle manufacturers, R&D organizations, fuel distributors, and consumers).

In parallel with the core enzymatic technology development at NREL, the Program supports other alternative conversion technologies such as acid hydrolysis activities at a number of private sector organizations (such as Arkenol), and a public organization, the Tennessee Valley Authority (TVA). In addition to ongoing activities at its national labs, the U.S. Biofuels Program is exploring niche market for biomass ethanol technology and is directly contracting partnerships with entrepreneurs from the private sector, who are willing to take the risk and co-share the cost of building the first generation of biomass ethanol plants. These include BC International, Arkenol, Masada Resources Group, and many others.

The Program is managed by the Office of Fuels Development within the DOE Office of Transportation Technologies (OTT). OFD provides centralized leadership and control for Program R&D activities. The Office of Fuels Development is responsible for policy formulation and allocation of technical and budgetary resources for research and development. At the end of each fiscal year, the Ethanol Program organizes a Technical Program Review by an outside Peer Review Panel composed of individuals from universities, State Energy Agencies, and the private sector. The purpose of this process is to review the technical progress for the Ethanol Program over the previous year, and assess the proposed new fiscal year activities relative to the overall Program Goals. The performance measures used by the experts to evaluate the program include: significance of the Scientific/Technical results; management of the research program; alignment of the program with national needs; and the effective use of resources.

2. PROGRAM JUSTIFICATION

There are several important reasons why the United States should aggressively pursue the development and commercialization of ethanol fuel derived from biomass. These reasons span the range of current national issues including the environment, energy security, and the economy. This National Program Plan for Biomass Ethanol plays a key role in assisting the Office of Transportation Technology (OTT)'s goals of reducing oil imports, strengthening the economy, improving the environment, and preserving personal mobility through R&D efforts in biomass feedstock and ethanol production technologies.

The U.S. Transportation Energy Problem

Crude oil and petroleum products represent about 40 percent of all energy consumption sources in the United States. The U.S. crude oil reserves are limited, and the domestic

Figure 2-1. U.S.Petroleum Production and Consumption, 1973-96

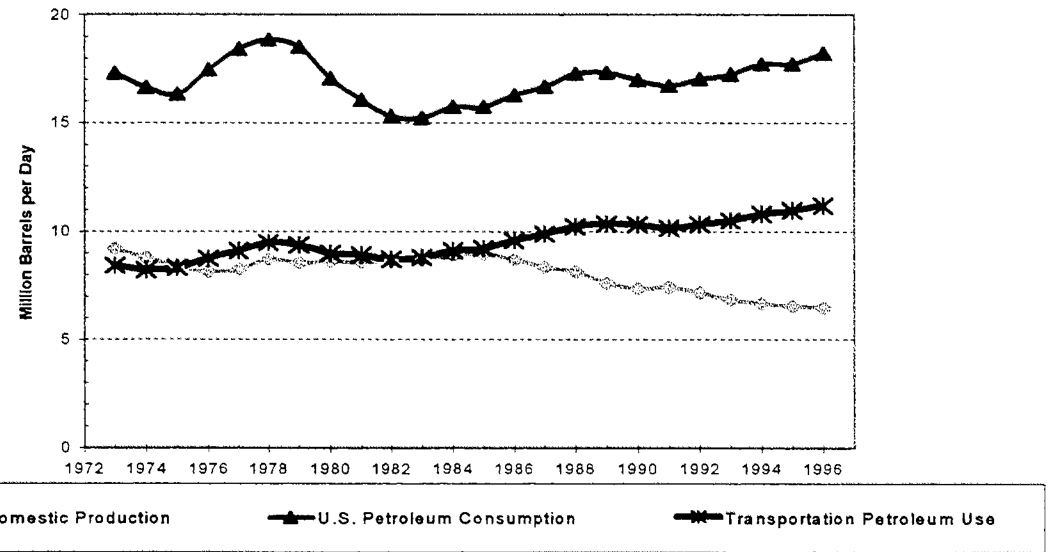
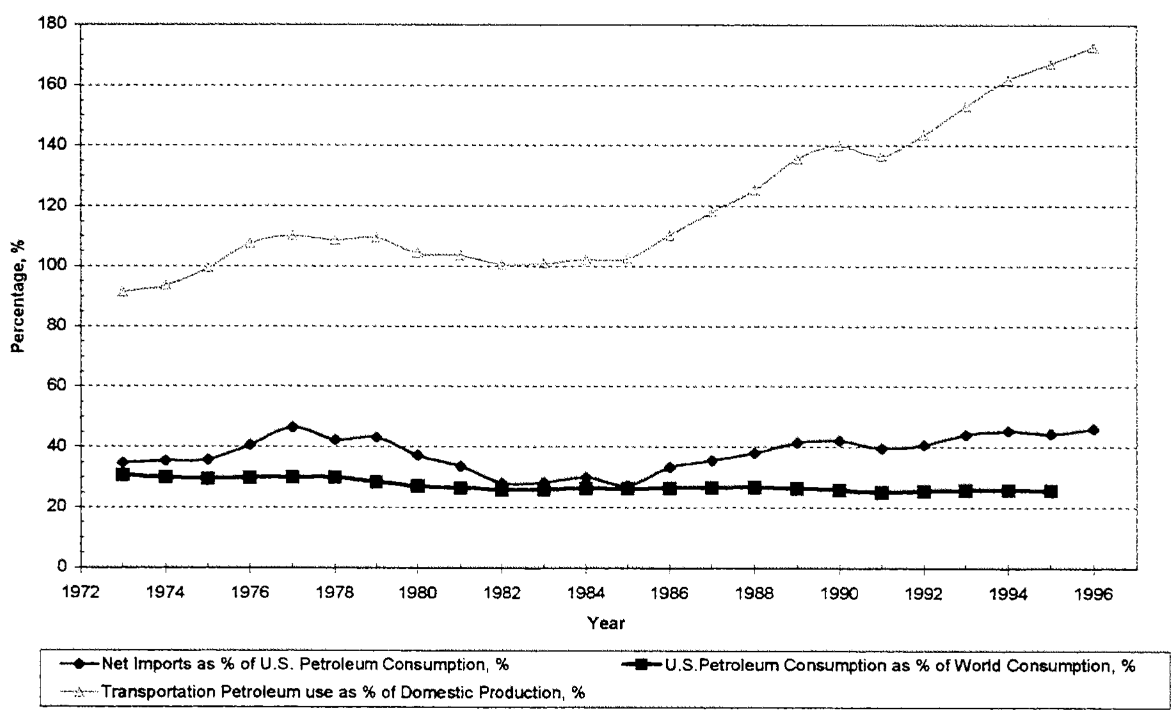
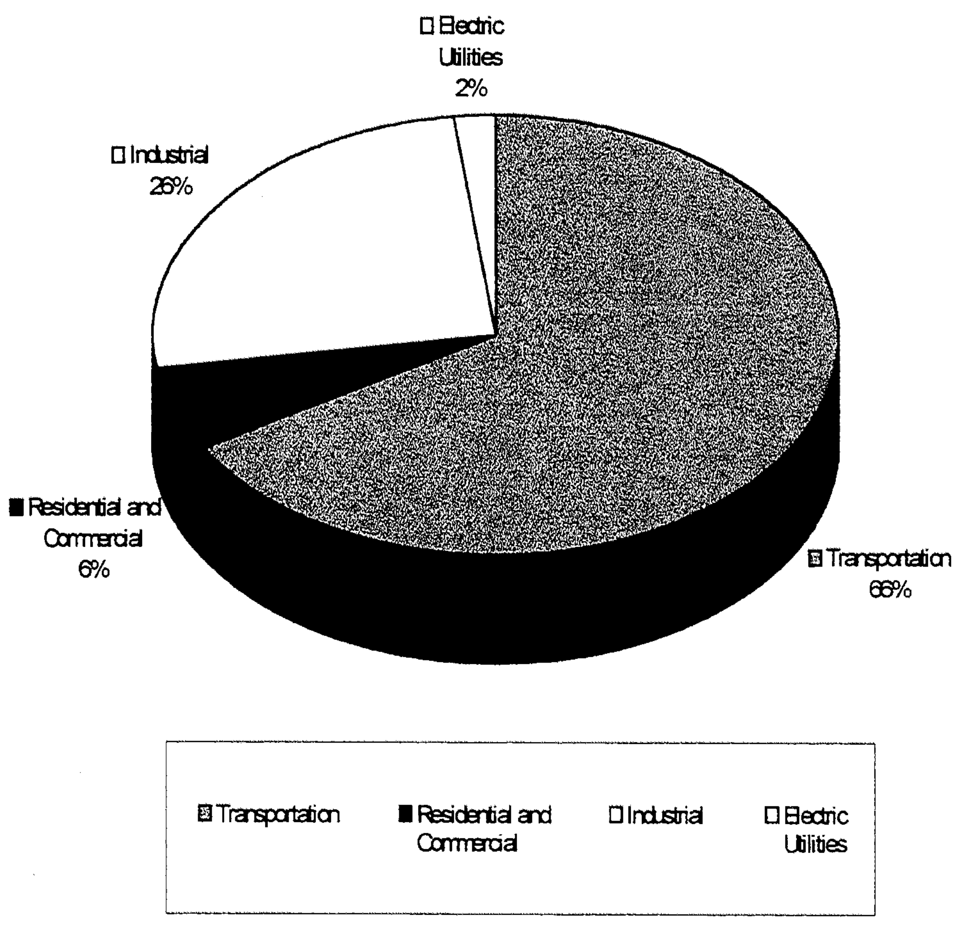


Figure 2-2. U.S. Petroleum Production and Consumption, 1973-96



petroleum production has been decreasing from 9.21 million barrels per day in 1973 to 6.47 million barrels per day[1] in 1996, Figure 2-1. During the same time frame, the U.S. petroleum consumption has increased steadily. In 1996, the U.S. petroleum consumption represented about 282 percent of the domestic production. Currently the United States consumes over 18 million barrels of petroleum each day for transportation and other uses. This is about 25 percent of the world's total consumption, yet the U.S. has less than 5 percent of the world's population, Figure 2-2.

Figure 2-3. Consumption of Petroleum by End-Use Sector for 1996



[1] U.S. DOE, Energy Information Administration, *"Monthly Energy Review"*, February 97, pp. 42-47.

In 1996, the transportation sector alone accounted for 66 percent of the total petroleum consumption by end-use sectors in the U.S.[2], Figure 2-3. Vehicle fuel efficiencies have shown steady improvement since the 1970s, but increases in population and per capita miles driven have more than offset these gains, causing total consumption of gasoline to rise by about 0.8 percent per year over the past 10 years. Still, cheap gasoline prices are encouraging us to drive more, and to purchase less fuel efficient vehicles such as sport utilities vehicles, pickups and vans, which together account for over 35 percent of the cars and light trucks in operation in the U.S.

The petroleum use by U.S. transportation sector has increased steadily in the 1973-1996 time frame, figure 2-2. In 1996, the amount of petroleum consumed by U.S. transportation sector represented 173 percent of the domestic production. The large gap between the domestic production and the national demand for petroleum products threatens the security of the United States.

Growing U.S. Dependence on Imported Petroleum

The U.S. imports about 55 percent of its oil supply. With consumption growing at over 1 percent a year and domestic production declining by about 3 percent annually, the Energy Information Administration predicts that by 2010 imports will account for 60% of our consumption. With this comes a significant transfer of wealth - reflected in the balance of payments. For 1997, net petroleum imports totaled $57.1 billions[3] and is projected to rise to $102.1 billions and $157.5 billion by 2020, respectively for low- and high-growth markets, Figure 2-4.

National Energy Security Concerns

By 2010, 60 percent of the oil traded on the international market will come from the Persian Gulf, a region of persistent political instability. As Daniel Yergin observed in his book _The Prize_, oil is a major factor in geopolitical struggles. Additionally, the rapid growth of economies among the world's developing nations, particularly in East Asia, means competition may greatly increase for petroleum on the world market. As living standards and mobility increase, and economies achieve desired growth, substantial growth in oil demand is forecast-- growth that may outstrip the ability to respond with inexpensive supplies. To the extent this occurs, increased global demand could lead to higher real energy prices in the United States, especially for oil.

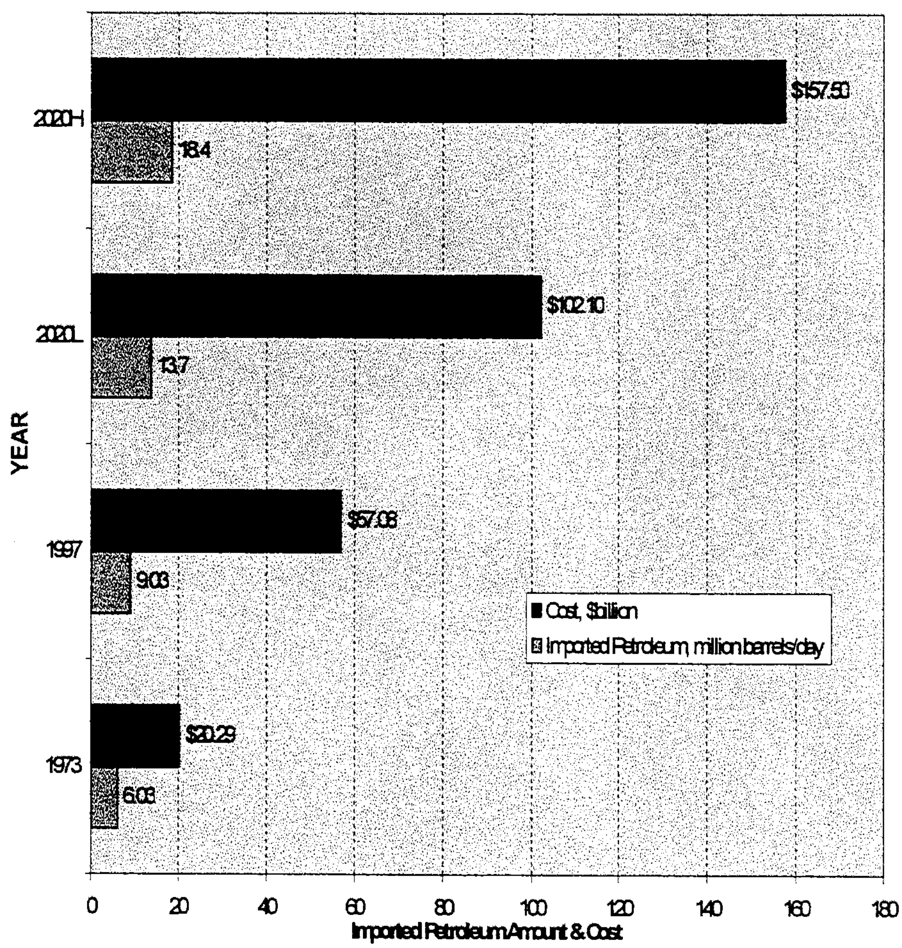
Economic Concerns

Imported oil costs the U.S. about $50 billion annually, is the biggest contributor to our trade deficit, and has a cumulative cost over the last 20 years of $1.3 trillion in current dollars. Oil imports deprive the U.S. economy of at least a million potential jobs. Total U.S. transportation energy consumption is expected to rise from 20 quads in 1996 to 35 quads in 2015 (EIA's Annual Energy Outlook, 1998), despite vehicle efficiency gains and the fact that global oil

[2] U.S. DOE, EIA, *"Monthly Energy Review"*, March 1997, pp.27, 29, 31, 33.
[3] U.S. DOE, EIA, *Annual Energy Outlook 1998"*, pp.66-67.

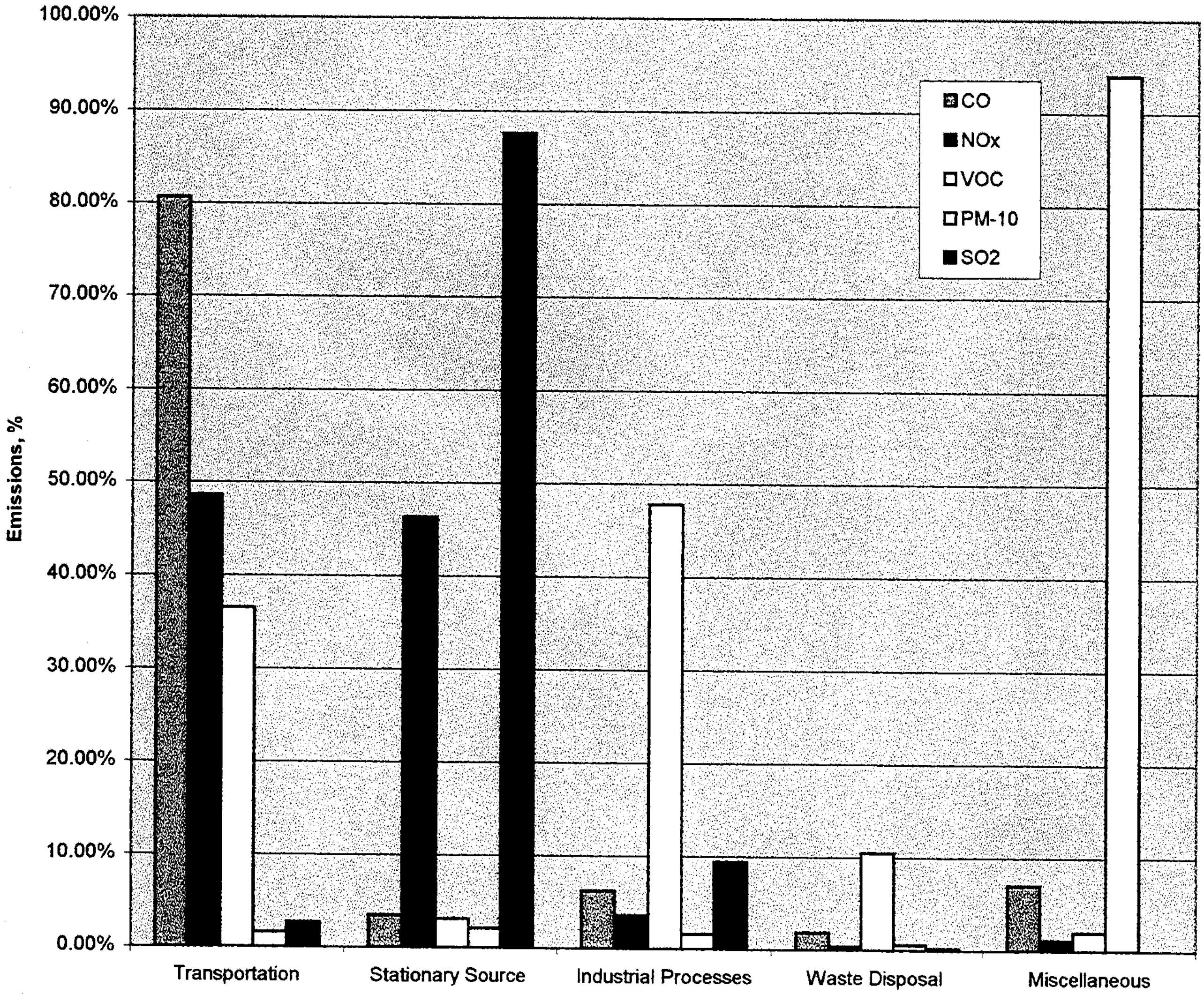
resources are finite and oil quality is deteriorating. Even if the Department of Energy forecasts a flat oil market in the foreseeable future, the ethanol market has a strong case because of perennial instability in the Mideast and because of increasing demand for oil by developing countries in Asia. This observation urges the Biofuels Program to diversify the fuel base in the U.S. transportation sector by intensifying R&D efforts to produce bioethanol, a domestically produced renewable fuel.

Figure 2-4. Growing U.S. Dependence on Imported Petroleum



The deployment of a cellulosic ethanol industry will revitalize rural economies by providing additional crop alternatives and new uses for agricultural residues (e.g. corn stover and forest residues). This will result in additional farm jobs, increased equipment sales, and employment which will enhance the economic base of our rural communities. The advances in genetic engineering of crops that result from our R&D efforts will benefit the agriculture, chemical, lumber, pulp and paper industries. The technologies also provide an international export opportunity to other countries, where fossil fuels are limited and/or markets exist for low carbon fuels.

Figure 2-5. Percent of U.S. Emissions by Sector, 1995



Environmental Concerns

In urban areas 80 percent of the pollution comes from energy used by transportation systems, and the American Lung Association estimated in 1988 that Americans spend $50 billion annually on health care resulting from air pollution. The Association is currently updating this estimate and has indicated that the cost today is considerably higher, not only due to rising health care costs, but also because understanding of the impacts of particulate emissions on the human body has dramatically improved. As emphasized in Figure 2-5, the transportation sector is responsible for 80 percent of the carbon monoxide emissions, 50 percent of nitrous oxides, 42 percent of the volatile organic compounds, and 32 percent carbon dioxide emissions in the U.S.[4, 5]

Concerns about Climate Change

The petroleum-based transportation sector is the largest source of carbon emissions in the U.S.[6], Figure 2-6. With concentrations of carbon dioxide 25 percent higher than in pre-industrial levels, the global potential for energy use to contribute to climate change has emerged as a new environmental risk. Increased atmospheric concentrations of greenhouse gases are likely to alter earth's climate system, although scientists do not agree on the timing and nature of potential climate changes, or on the scope and severity of the problems associated with a changing climate system.

When cellulosic biomass is used in ethanol production, CO2 is recycled in closed loop between ethanol and biomass and there is no net accumulation of CO2. In addition, biomass burning has been cited as one of the major anthropogenic interferences with the climate system. Catastrophic forest fires release large amounts of greenhouse gases to the troposphere. Ethanol production from the softwood accumulated from thinning national forests would reduce the potential and severity of these fires.

Legislative/Regulatory Drivers

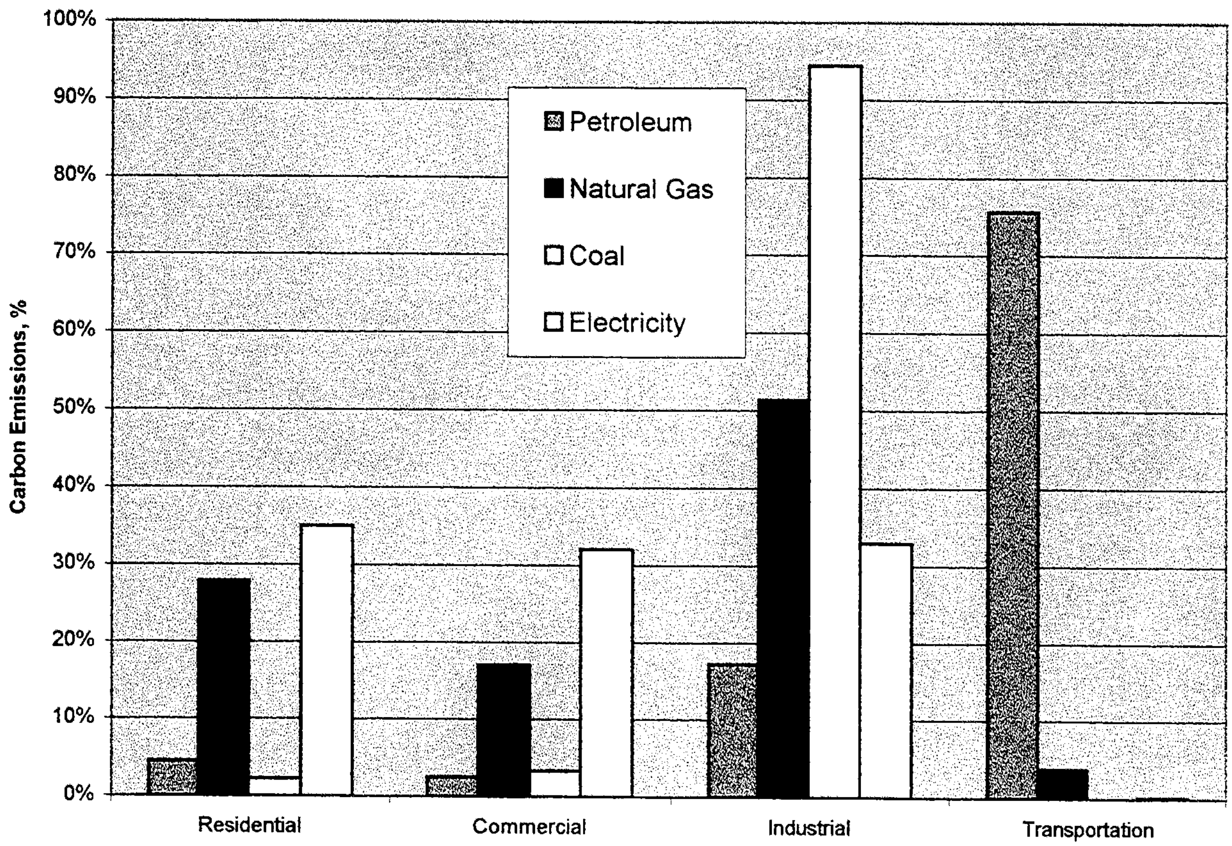
Major forces behind the evolution of ethanol as a transportation fuel include a series of Federal laws shown in the Box[7], that began in 1978 as well as the Clean Air Act of 1963 and its subsequent Amendments (CAAA), enacted in 1970, 1977, and 1990.

Under Section 502(b) of the Energy Policy Act of 1992 (EPACT), Congress has set goals of 10 percent fuel displacement by 2000 and 30 percent fuel displacement by 2010. EPACT defines replacement fuels as the portion of any motor fuel that is, ethanol, other alcohols, ethers, or any other alternative fuel the Secretary of Energy determined, by rule, is substantially not petroleum and would yield substantial energy security benefits and substantial environmental benefits when used as a replacement for petroleum in the transportation sector. The Clean Air Act Amendments (CAAA) of 1990 requires the addition of oxygenates such as ethanol to gasoline in

[4] U.S. EPA, *"National Air Pollution Emission Trends, 1900-1995"*, 1996, Appendix A.
[5] U.S. DOE, EIA, *"Annual Energy Review 1997"*, p.305.
[6] Ibid., pp. 308-309.
[7] EIA/Estimates of U.S. Biomass Energy Consumption, May 1994

areas that exceed public health standards for ozone and CO, known as nonattainment areas. Today approximately 35% of the nation's gasoline contains some level of oxygenates in order to reduce harmful emissions and improve our nation's air quality.

Figure 2-6. Petroleum-Based Transportation Sector is the Largest Source of Carbon Emissions in the U.S. (1996)



Legislative Acts that Have Contributed to the Use of Ethanol as a Fuel

- **Energy Tax Act of 1978,** Section 4081: defined gasohol as a blend of 90 percent gasoline and 10 percent renewable-derived alcohol and established a motor fuel excise tax exemption of 4 cents per gallon for it through October 1, 1984.
- **Energy Security Act of 1980:** authorized funds for building alcohol fuel production plants.
- **Crude Oil Windfall Profit Tax of 1980:** extended the 4-cents-per-gallon tax exemption for gasohol to December 31, 1992, and established a blender's tax credit of 40 cents per gallon of fuel blend for the use of alcohol in any proportion other than 10 percent alcohol/90 percent gasoline.
- **Omnibus Reconciliation Tax Act of 1980:** placed a tariff on imported fuel ethanol/gasoline blends that was equivalent to the blender's tax credit established by the Crude Oil Windfall Profit Tax of 1980.
- **Surface Transportation Act of 1982:** raised the gasoline tax from 4 cents per gallon to 9 cents per gallon and increased the exemption for gasohol to 5 cents per gallon.
- **Deficit Reduction Act of 1984:** increased the tax exemption for gasohol to 6 cents per gallon and increased the blender's tax credit to 60 cents per gallon of blend.
- **Alternative Motor Fuels Act of 1988:** encouraged the use of alternative fuels, including ethanol, and addressed national energy policy concerns.
- **Budget Reconciliation Act of 1990:** reduced the gasohol tax exemption to 5 cents per gallon and the blender's tax credit for ethanol to 54 cents per gallon. It extended these incentives to the year 2000. The law provided a credit of 10 cents per gallon for the first 15 million gallons of ethanol manufactured by qualified small producers with annual outputs of less than 30 million gallons.
- **Clean Air Act Amendments of 1990:** mandated the use of oxygenates in gasoline sold in carbon monoxide and ozone nonattainment areas.

Energy Policy Act of 1992: set guidelines and established incentives to encourage the increased use of alternative fuels and alternative-fueled vehicles in Federal, State, and private fleets. It preserved the 5-cents-per-gallon Federal motor fuel excise tax exemption for g

- sohol and the 54-cents-per-gallon blender's income tax credit for ethanol.

Source: EIA/Estimates of U.S. Biomass Energy Consumption, May 1994

Tax Incentives Drivers

According to the Energy Information Administration (EIA/Estimates of U.S. Biomass Energy Consumption 1992), gasoline blends containing at least 10 percent ethanol (gasohol) received a Federal tax exemption of 6 cents per gallon of blend during 1992. This exemption provided ethanol with a market subsidy of approximately 60 cents per gallon. That subsidy was equal to about $25 per barrel of ethanol but, when the energy difference is considered, the subsidy was equal to about $40 per barrel of gasoline displaced. In addition, individual State incentives, primarily in the form of tax exemptions, were made available to producers and/or retailers. The tax exemption range from 1 cent per gallon of fuel blend to 8 cents, equal to an ethanol-equivalent market incentive of 10 to 80 cents per gallon of ethanol (see Table 2-1).

Table 2-1. States with Ethanol Tax Incentives[8]

State	Ethanol tax incentives
AK	$0.08/ethanol gallon (blender)
CA	E85 and M85 excise tax is half of the gasoline tax. Neat alcohol fuels are exempt from fuel taxes.
FL	County governments receive waste reduction credits for using yard trash, wood, or paper waste as feed stocks for fuel.
HI	4% ethanol sales tax exemption
ID	$0.21 excise tax exemption for ethanol or biodiesel
IN	10% gross income tax deduction for improvements to ethanol producing facilities
IL	2% sales tax exemption for 10% volume ethanol blends
IA	$0.01 (blender)
MN	$0.25 (producer), $0.005 (blender) until October 1, 1997
MO	$0.20 (producer)
MT	$0.30 (producer)
NE	$0.20 (producer), $0.50 ETBE (producer)
NC	Individual income and corporate tax credit of 20% for the construction of an ethanol plant using agricultural or forestry products; an additional 10% if the distillery is powered with alternative fuels.
ND	$0.40 (producer)
OH	$0.01 (blender), income tax credit
SD	$0.20 (blender), $0.20 (producer). Alternative fuels are taxed at $0.06/gal
WY	$0.40 (producer)

Source:
U.S. Department of Energy, *Clean Cities Guide to Alternative Fuel Vehicle Incentives and Laws*, 2nd edition, Washington, DC, November 1996.

3 R&D ACTIVITIES FOR BIOMASS FEEDSTOCK DEVELOPMENT

The objective of the Bioenergy Feedstocks Development Program (BFDP)[9,10] is to develop and demonstrate environmentally acceptable crops and cropping systems for producing large quantities of low-cost, high-quality biomass feedstocks. The crop development research is complemented by resource assessments, economic analysis, and

[8] U.S. Department of Energy, *Clean Cities Guide to Alternative Fuel Vehicle Incentives and Laws*, 2nd edition, Washington, DC, November 1996.

[9] *FY98 Annual Operating Plan (AOP). Bioenergy Feedstock Development Program*. Prepared for the U.S. Department of Energy, Office of Fuels Development (OFD), Biofuels Program. Prepared by the Bioenergy Feedstock Production Program, Environmental Sciences Division, Oak Ridge National Laboratory (ORNL). Oak Ridge, Tennessee. January 20, 1998.

[10] *Biofuels Program Summary*. U.S. Department of Energy, Office of Fuels Development (OFD). July 16, 1998.

environmental research and analysis that provide the information needed to demonstrate and commercialize biomass energy systems. Through BFDP, OFD has screened more than 125 tree and nonwoody species and selected a limited number of model species for development as energy crops. National goals include:

- Commercial-scale supply of perennial crop biomass to an ethanol plant at $37/dry ton by 2005.
- Viable biomass production , handling and delivery systems on 1 percent of cropland (3 million acres) at $37/dry ton by year 2015 with environmentally acceptability.
- Viable biomass production, handling and delivery systems on 4 percent of U.S. cropland (12 million acres) at $37/dry ton by 2025 with environmental acceptability.

Strategic Objectives to Achieve Program Goals Include

- Focus on two model species, one woody and one herbaceous crop.
- Create regional feedstock development centers or consortia for 4 regions (North Central, South, Southeast, and Northeast).
- Facilitate partnering between farmers and potential commercial ventures for producing ethanol from cellulosic materials.

3.1 Niche Feedstock Development Targets

The year 2000 target is based on identification, evaluation, and conversion of near-term feedstocks based on niche environmental opportunities. Niche feedstocks are associated with an existing industry and are low or negative cost byproducts from the processing of biomass into the primary product. These feedstocks provide an opportunity to establish early biomass-to-ethanol facilities because of feedstock cost and association with standing facilities that reduce capital cost. Table 3-1 shows major near-term niche feedstocks currently under consideration for various collaborative research opportunities, as well as the industry partner committed to take the technology to the market.

Table 3-1. Major Near-term Feedstocks under Consideration for Year 2000 Core Technology Development

Near-term Feedstock	R&D Project
Rice Straw	Arkenol, Inc.'s project in Sacramento, CA
Rice Straw	BC International project in Gridley, CA
Sugarcane Bagasse	BC International plant in Jennings, LA
Municipal Solid Wastes	Masada Resources Group project in Middletown, Orange County, NY
Softwoods	The Quincy Library Group project in Northeastern California
Corn Stover	Bridge to Corn Ethanol Industry

Softwoods are among the most interesting near-term feedstocks identified for the year 2000. Current Biofuels Program R&D efforts focus on designing pretreatment methods and fermentation technology optimized for the conversion of softwoods. Among the various waste sources of softwoods, forest residues deserve a special mention because they represent a pressing environmental issue in many parts of the U.S. Efforts to protect national forests from the ravages of fire create large amounts of waste (forest thinnings) which, when given appropriately dry conditions, are producing devastating forest fires. Many western states are seeking new approaches to controlled burns in these forests. Converting this residue into bioethanol may prove to be win-win solution for forestry officials and the fledgling bioethanol industry.

Rice straw is another example of an immediate environmental problem that could be turned into an opportunity for bioethanol. California's rice growers are no longer permitted to burn rice straw in field, posing a problem for disposal of this residual material. We have identified partners in California who are developing technology and business plans for rice straw derived bioethanol.

3.2 Dedicated Feedstock Development Targets

In the mid- to long-term, the Feedstock Development Program focuses on the development of two model perennial crops: switchgrass as a model for herbaceous crops and hybrid poplar as a model for short-rotation energy crops. These crops were selected because they grow rapidly and can be grown across several regions and sites in the United States. Energy crops have advantages from an environmental perspective in terms of carbon recycling and sequestration, erosion control compared to traditional agricultural row crops, and the potential for using marginal agricultural land to expand the agricultural base in the U.S.

3.2.1 Herbaceous Energy Crops

Herbaceous energy crops include warm-season grasses and other groundcover perennials that could be harvested and converted to energy. The R&D activities on herbaceous energy crops have focused on switchgrass as a model feedstock because of its adaptability to a wide range of environments, its drought tolerance, and its extensive root system that helps prevent soil erosion. Its high yields and flexibility as both a forage and energy crop make it an attractive choice.

3.2.2 Short-Rotation Woody Crops (SRWC)

Short-rotation woody crops (SRWC) represent a new spin on an old source of energy. Instead of taking wood from forests, trees would be cultivated and harvested specifically for energy use. ORNL has evaluated varieties of trees that adapt best to growing as energy crops. Their tests have been held in different parts of the country to learn what trees grow best in different areas. Much of the research has focused on hybrid poplar species, which has been chosen as the model feedstock for the short rotation woody crops. Current research by ORNL focuses on producing woody crops that are highly productive under short rotations of 4-7 years, and that have low requirements for nutrients, water, herbicides, and pesticides. Efforts include developing tree strains that offer high yield, adapt to large- scale field trials, and are resistant to insects and disease. Researchers use genetics to develop hybrids that encourage desirable characteristics. Cloning allows the most successful plants to be reproduced.

3.2.3 Likely Bioenergy Crops Produced by Region

As stated above, in the long-term, the dedicated bioenergy crops currently receiving the greatest attention include switchgrass, hybrid poplar trees, and willow trees. Table 3-2 indicates the types of bioenergy crops that can be produced in each region of the country: (Note: Bioenergy crops can be produced in additional regions, such as the Delta States, but yields data in these regions is unavailable).

Table 3-2: Likely Bioenergy Crops Produced by Region

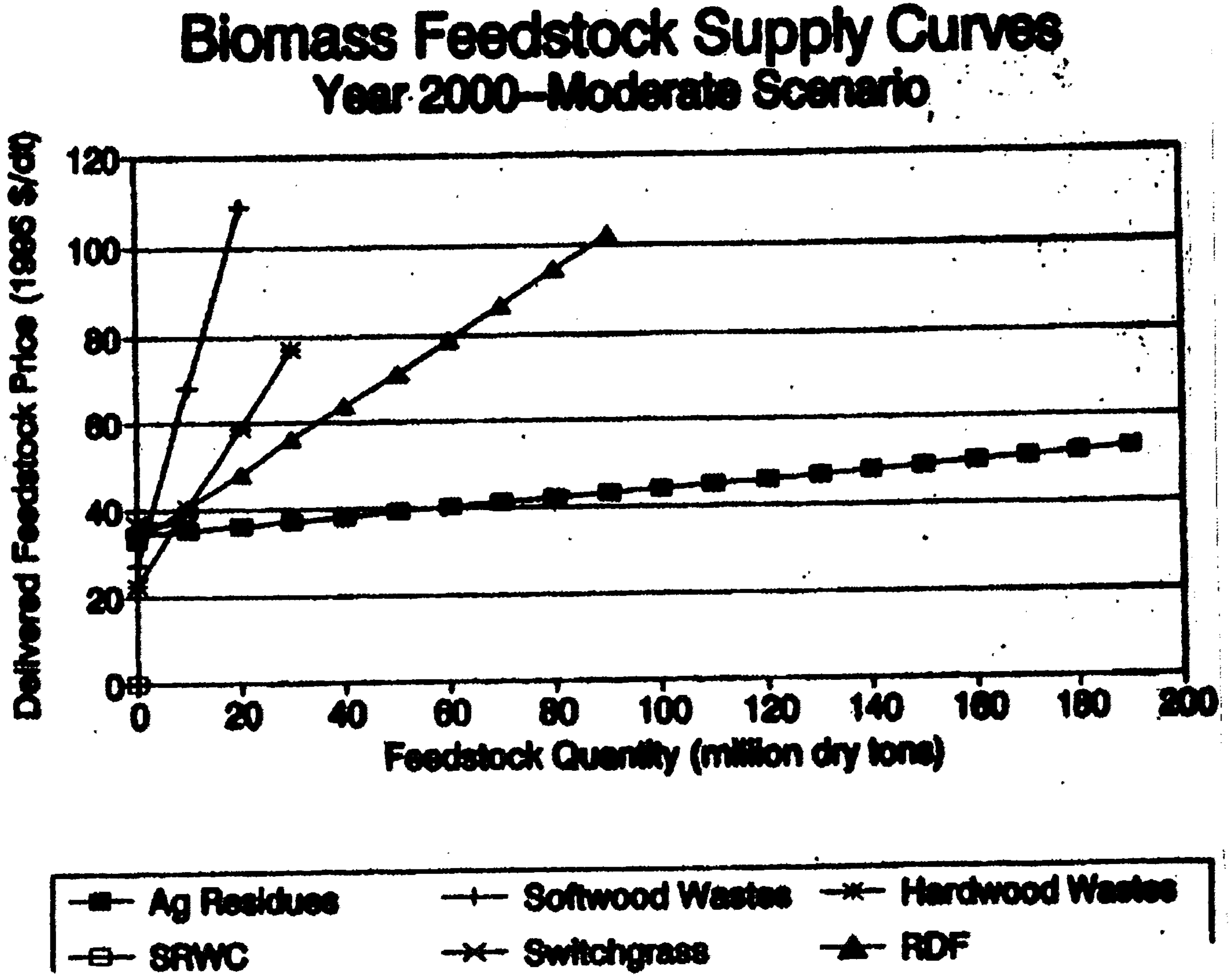
Region	Likely Bioenergy Crops
Lake States (MI,MN,WI)	Switchgrass, hybrid poplar, willow
Corn Belt (IA,IL,IN,MO,OH)	Switchgrass, hybrid poplar
Appalachia (KY,NC,TN,VA,WV)	Switchgrass, hybrid poplar
Southeast (AL,GA,SC)	Switchgrass, hybrid poplar
North Plains (eastern half of KS,NE,ND,SD)	Switchgrass, hybrid poplar
South Plains (eastern half of OK,TX)	Switchgrass, hybrid poplar
Northeast (PA,NY)	Willow
Pacific Northwest (OR,WA)	Hybrid poplar

3.3 Estimation of National Biomass Feedstock Supply Curves

Using the BIOCOST Model, ORNL researchers[11] have estimated the plant-gate cost of supplying biomass feedstocks to ethanol production plants, and the share of the total fuel ethanol market supplied by corn and several cellulosic feedstocks. The feedstocks covered by the study included dedicated energy crops (hybrid poplar, willow, and switchgrass), agricultural residues (wheat straw and corn stover), forest residues (softwoods and hardwoods), corn, and refuse derived fuel (RDF). The study covered the time frame from 2000 to 2015, assuming moderate and optimistic scenarios for ethanol demand quantities. Figure 3-1 shows typical feedstock supply curves, estimated for the year 2000 under moderate ethanol demand scenario.

Figure 3-1. Biomass Supply Curve
Moderate Scenario -- Year 2000

[11] Walsh, M.; Becker, D.; and Graham,R. *"Feedstock Supply Curve Analysis"*. Oak Ridge National Laboratory (ORNL) for the Office of Fuels Development Program Review, February 11-12, 1998.


Biomass Feedstock Supply Curves
Year 2000--Moderate Scenario
Delivered Feedstock Price (1995 $/dt)
0
20
40
60
80
100
120
0
20
40
60
80
100
120
140
160
180
200
Feedstock Quantity (million dry tons)
Ag Residues
Softwood Wastes
Hardwood Wastes
SRWC
Switchgrass
RDF

3.4 Major Feedstock Development R&D Activities

MAJOR FEEDSTOCK DEVELOPMENT R&D ACTIVITIES

- Biomass Feedstock Development Centers
- Environmental Effects of Energy Crop Deployment
- Energy Crop Seedling/Planting Stock Selection Research
- Large Scale Woody Crop Plantation Research
- Switchgrass Variety Testing and Scale-up Research
- Mechanization Research
- Consortium for Plant Biotechnology Research

3.4.1 Biomass Feedstock Development Centers

Through its Biomass Feedstock Development Centers, the program will continue to fund and conduct research to develop economically viable model energy crops. These centers are currently located in the Pacific Northwest (poplars), Southeast (switchgrass), and Midwest/Plains States (switchgrass and poplars). Research on developing willow trees as viable energy crop will also continue in the Northeast/Lake States. In 1999, work at the centers will focus on breeding research aimed at selecting higher yields and other desirable traits. Center research will be closely linked with studies on crop management, physiology, growth-limiting factors, and advanced biotechnology. It is anticipated that research and developments efforts associated with the Biomass Feedstock Development Centers cost approximately $3.3 million in FY 1997 and $1.5 million in FY 1998. In FY 1999, costs are expected to increase to $4.5 million.

In-depth studies on the optimal locations for Switchgrass/Ethanol Facilities are being conducted in four to five regions of the US in order to insure that the developing cellulosic ethanol industry will have adequate flexibility in choosing suitable locations. The five regions include the North Central region, the Northeastern region, the Northeast/Lake region, the South Central region, the Southeast region and the Mid-Atlantic region. At least one fully integrated crop development center is desirable for each region. Based on the results of these studies, program officials will determine the number of ethanol facilities that can be supported in these locations and begin to assess the resources needed to make these facilities operational. This effort cost $100,000 in FY 1997.

3.4.2 Environmental Effects of Energy Crop Deployment

During the 1997-1998 time frame, program researchers initiated efforts to assess the effects any large-scale deployment of energy crops will have on the environment. Their primary objective is to design and conduct assessments that will provide credible data to program managers. This data will then be used to guide deployment in a manner that preserves the energy and environmental benefits associated with crop deployment. In 1999, research will continue in the evaluation of established experimental sites in the areas of water and soil quality effects, chemical fates, and biodiversity. The costs to assess the environmental impacts of large-scale crop deployment were approximately $500,000 in 1997 and $413,000 in 1998. In 1999, the level of effort in this area will decline with expected expenditures of $225,000 for the year.

3.4.3 Energy Crop Seedling/Planting Stock Selection Research

Using advanced biotechnology and other methods, program researchers will focus on identifying techniques that can be used to select energy crop seedlings or other planting stock that are less susceptible to disease and/or pests. The resulting stock will be at a reduced mortality risk thus increasing the technical and economic viability of the program. Researchers will continue to develop and apply tissue culture techniques to select and propagate desired genotypes of switchgrass. In FY 1997, OFD spent approximately $300,000 on efforts in this area. OFD expects additional expenditures of $100,000 in both FY 1998 and in FY1999.

3.4.4 Large Scale Woody Crop Plantation Research

In FY 1997 and FY 1998, OFD intends to continue efforts towards researching and evaluating large scale woody crop management techniques. Currently, water use efficiency issues constrain the development of large scale woody crop plantations, especially in the Southeast. Also in FY 1998, and into FY 1999, OFD will take an active role in providing technical assistance and cost sharing for large scale plantings in the Midwest/North Central region. Their objective will be to obtain performance and cost data that will be useful in estimating costs for large scale plantings in other regions. Costs are expected to average $150,000 annually through FY 1998. The level of effort will decline slightly in FY 1999 with expenditures of approximately $125,000.

3.4.5 Switchgrass Variety Testing and Scale-up Research

During 1997, program managers will oversee the establishment of new switchgrass variety tests in locations that have been identified as having high potential for technical and economic viability of these crops, but currently have little data. The data resulting from these test sites will be useful in developing the best clones or varieties specifically adapted to the variable conditions in the major growing regions of the U.S. Variety tests will continue throughout FY 1998 and FY 1999. Also in FY 1999, the program will initiate cost-shared 100 to 300 acre scale-up plantings of switchgrass in the Midwest or South regions. These planting will provide program managers with vital yield, operational and cost data. Expenditures in this area averaged $200,000 for FY 1997 and FY 1998. OFD is expecting a significant ramping up of activity in FY 1999 and have budgeted $900,000 to assist them in obtaining the available data from the cost-shared planting and applying that information to potential cost-sharing arrangements in other regions of the country.

3.4.6 Mechanization Research

A major obstacle to the widespread acceptance of energy crops for ethanol consumption is the high cost of harvesting and handling the crop relative to similar costs for conventional crops such as corn and wheat. During the FY 1997-1998 timeframe, program managers' focus was to identify and evaluate mechanization systems that have the potential to lower harvesting and handling costs of energy crops. In FY 1999, OFD's goals are to develop a number of cost-shared opportunities for switchgrass handling and storage with the primary objective of reducing the ethanol production costs. Activity costs are expected to be $50,000 in each of the first two years with an increase to $150,000 in FY 1999.

3.4.7 Consortium for Plant Biotechnology Research

Initiated in 1985, this is a multi-million dollars jointly-funded feedstock research effort represented by over 38 corporate members (such as Heinz, Monsanto Co., Proctor and Gamble, Weyerhauser, etc.), 22 universities, government agencies, and national laboratories. Through this consortium, OFD is able to leverage its resources to undertake research that is meaningful to industry and within the scope of the MYTP technical goals and objectives. OFD's primary objective over the FY 1997 to FY 1999 time period is to conduct cost-shared (50%- 50%) long term research and development projects with the Consortium for Plant Biotechnology Research. In working with the consortium, the program will benefit from high-quality, peer- reviewed university research which will have practical applications in the biofuels development process. OFD anticipated spending $1.1 million in FY 1997 to continue their relationship with the consortium. In FY 1998, the expected level of funding increases to $2.5 million and then declines to approximately $1.0 in FY 1999.

3.5 Partnerships with Industry and Others

As USDA assumes greater responsibility for regional crop breeding and testing efforts, DOE/ORNL's role will focus on working collaboratively with universities, USDA, and private industry to provide the basic research information required to continue risk reduction for the biomass ethanol industry.

DOE and several partners from industry, the Federal sector, and local government are continuing collaborations on biomass feedstock development and demonstration projects involving short-rotation woody crops to ensure that a cost-effective feedstock base will be available. Through various consortia, pulp and paper companies are cofunding projects with contributions which are twice the size of DOE's.

Demonstrating "feasibility of profitable, sustainable" perennial crop production on a small research budget requires making astute choices in locating research and development activity. DOE/ORNL initially sought only the best expertise around the country for developing new crops and cropping techniques. The challenge now is to combine the best research expertise with optimum crop production locations to achieve commercial success in 2005 by supplying perennial crops to an ethanol plant at $37/ton dry biomass. Determination of optimal (lowest-cost, environmentally acceptable) perennial crop production locations is being done by combining the available yield and environmental effects data from experimental field trials with geographically specific information on alternate land use and transportation networks (GIS modeling). Collaborative efforts are also ongoing to integrate perennial crops into USDA agricultural models. Both the GIS and USDA model outputs will aid decision-making on the location of regional trials and large-scale crop evaluations

3.6 Feedstock Development Program Milestones

Table 3-3. Feedstock Development Milestones

YEAR	PLANNED ACTIVITIES
1998	Initiate larger scale switchgrass test sites in the southern U.S. for validating yields and costs of switchgrass production.
	Implement new switchgrass breeding strategies to support future ethanol production
	Collaborate with Biomass Power Program on initiating economic study of 2 large-scale switchgrass plantings
1999	Document achievement of 100,000 acres of commercial short-rotation, woody crops and relationships to DOE-supported SRWC research
	Begin tests of promising, newly bred switchgrass selections at 6 test sites at USDA Plant Materials Centers in the South East and North Central regions
2000	Continue genetic transformation R&D on poplars in collaboration with fiber industry, and release new clones to private nurseries in North Central region
	Initiate R&D on switchgrass handling systems with equipment manufacturers to improve reliability and quality, and reduce costs
	Establish switchgrass field trials near an existing ethanol plant with participation of local Universities
2001	Initiate R&D on switchgrass pests and pathogens
	Document economic results from Biomass Power's switchgrass plantings for co-firing demonstrations initiated in 1998 and 1999
	Initiate wide geographic crosses among southern poplar accessions using region-wide germ plasm collections
2002	Initiate commercial production of switchgrass seeds from best DOE-funded selections from USDA Plant Materials Centers
	With Dept. of Agriculture, complete economics model of biomass crops as part of agricultural and forestry sectors
2003	Complete testing of switchgrass harvesting systems and develop regional recommendations for least-cost harvesting and handling options
	Establish switchgrass partnerships with ethanol producers and farmers; conduct small scale field testing in targeted locations
	Evaluate establishment success and productivity of wide crosses of poplars on a range of sites across the south

4. BIOMASS-TO-ETHANOL CONVERSION TECHNOLOGY

Mankind has been making ethanol for thousands of years: fermenting sugars and starches into beverage alcohol was one of the first complex biological and chemical processes that man mastered. In the 19th century, ethanol was widely used as a fuel for lamps and in internal combustion engines once it was introduced. However, with discoveries of petroleum and the decline in the cost of petroleum products at the turn of the century, gasoline became the dominant liquid fuel. Since then, the use of ethanol as a fuel and ethanol/gasoline blends occasionally surfaced to consume wartime surpluses (World War I), to supplement petroleum shortages (World War II), and to assist a severely depressed agriculture (i.e., during the 1920s and 1930s). A renewed interest in ethanol use occurred during the 1970s as a result of sharp increases in oil prices and disruption in foreign oil supplies. Although oil prices have since moderated, the discovery of ethanol's utility as an octane enhancer, the mandatory phase-down of lead in gasoline, the Clean Air Act Amendments of 1990 which mandate the use of oxygenates in CO and ozone nonattainment areas[12], and other drivers described earlier, have helped to maintain a level of demand for fuel ethanol equivalent to almost one percent of U.S. gasoline usage[13].

4.1 Conversion of Sugar Crops to Ethanol

Sugar crops can be directly fermented into ethanol. The most common sugar crops used as feedstock for ethanol production in the United States include sugarcane, sugar beets and sweet sorghum. Sugar crops can produce 18.5-23.7 gallons of ethanol per ton.[14] Sugarcane is attractive as an ethanol feedstock because of the high sugar yield and low production cost. But sugar, while more readily fermentable than grain, is not an economic feedstock for U.S. ethanol production at current prices. In the United States, it is much more profitable to harvest crops for sugar than for ethanol production. But the bagasse left over after pulp extraction may become a near-term feedstock for ethanol production.

4.2 Conversion of Corn and Other Grains to Ethanol

Current U.S. ethanol production capacity amounts to 1.6 billion gallons of ethanol per year. Corn is the most commonly used feedstock for fuel ethanol production in the United States, representing over 90% of the total ethanol production capacity. It is possible to use other grains such as wheat, barley, grain sorghum and tubers such as potatoes and sweet potatoes. Corn's conversion rate into ethanol is better than any other grain: 2.5 gallons of ethanol per bushel of grain. However, all these grain crops generally have a higher market value for uses other than ethanol production for fuel.

[12] Tshiteya, R.M. "Alcohol Fuels Reference Work #2: Emission Characteristics of Alcohols and Alcohol-Fueled Vehicles". Meridian Corporation for National Renewable Energy Laboratory (NREL), June 1992, pp. 4-6 to 4-11.
[13] EIA: "Alternatives to Traditional Transportation Fuels 1996, December 1997 (with estimates for 1998)".
[14] Jaycor, "Worldwide Review of Biomass-Based Ethanol Activities", 1986, p.50.

4.3 Conversion of Cellulosic Biomass to Ethanol

While the conversion of sugar and grain crops to ethanol is a proven technology, the conversion of cellulosic biomass to ethanol is still a subject of intensive research and development efforts. Currently there is no biomass-to-ethanol conversion plant in the U.S. The conversion needs of cellulosic biomass feedstock are composition-specific. The efficient conversion of cellulosic biomass to ethanol requires a thorough understanding of the chemical and physical properties of the biomass feedstock. Table 4-1 shows the composition of three typical cellulosic biomass species being considered by the Biofuels Program for conversion to ethanol. These are a hardwood species (hybrid poplar), a herbaceous species (switchgrass), and agricultural residue species (corn stover and corn cobs).

Table 4-1. Composition (in wt%, dry basis) of Representative Biomass Species Being Considered for Conversion to Ethanol[15,16,17]

COMPONENT	HARDWOOD Poplar Hybrid	HERBACEOUS Switchgrass	AG/RESIDUES Corn Stover	AG/RESIDUES Corn Cobs
Glucan	51.8	36.6	40.9	39.4
Xylan	11.3	16.1	21.5	28.4
Arabinan	0.3	2.2	1.8	3.6
Galactan	0.7	1.2	1.0	1.1
Mannan	0.3	0	0	0
Klason Lignin	22.5	21.9	16.7	17.5
Acetyl Groups	1.9	1.1	1.9	1.9
Other	11.2	20.9	16.2	8.1
Total Carbohydrate	**64.4**	**56.1**	**65.2**	**72.5**

These biomass species are comprised of a complex mixture of cellulose, hemicellulose, lignin, and a small amount of other compounds. Cellulose is mainly made up of glucan (a polymer of

[15] Torget, R.; Walter, P.; Himmel, M.; and Grohmann, K. *Ethanol Annual Report FY 1990.* SERI/TP-231-3996. UC Category: 241. DE91002125. January 1991, pp. 71-82.
[16] Torget, R.; Werdene, P.; Himmel, M.; Grohmann, K. *Appl. Biochem. Biotechnol.* 1990, 24/25, 115-134.
[17] Torget, R.; Himmel, M.; Grohmann, K. *Appl. Biochem. Biotechnol.* 1992, 34/35, 115-124.

six-carbon sugar units), while hemicellulose is made up of mainly xylan (a polymer of five-carbon sugar units), and small amounts of arabinan (a polymer of five-carbon sugar units), galactan and mannan (two polymers of six-carbon sugar units). These complex carbohydrates can be converted to simple fermentable sugars: glucose, xylose, arabinose, galactose, and mannose, respectively. As shown in the Table, the carbohydrate content of these biomass species varies from 56% to 72.5% of the dry mass. The lignin content varies from 16.7% to 22.5% of the dry mass, while ash and other minor components make up the balance.

Each cellulose molecule is a linear fiber made up of molecules of D-glucose (a six-carbon sugar) held together by β-glycosidic bonds[18]. The cellulose fibers form bundles of parallel chains. Adjacent chains are bound together by hydrogen bonds between hydroxyl groups and hydrogen atoms, resulting in a crystalline structure that renders cellulose more difficult to hydrolyze than hemicellulose or starch. Hemicellulose is mainly composed of molecules of five-carbon sugars such as xylose and arabinose, and molecules of six-carbon sugars D-glucose, D-manose and D-galactose. Its individual chains are branched resulting in a non-crystalline structure. Therefore, unlike cellulose, hemicellulose is readily hydrolyzable. However, while the six-carbon sugars are readily fermentable to ethanol, the five-carbon sugars cannot be fermented to ethanol by standard industrial yeasts such as saccharomyces cerevisiae. The Biofuels Program is conducting an impressive research to develop improved microorganisms capable of fermenting the 5-carbon sugars contained in the biomass structure. Lignin, which is a three-dimensional amorphous branched polymer based mainly on the phenylpropane unit, is not a sugar and thus cannot be fermented to ethanol. The lignin protects the cellulose from attack and degradation. Starch, the main component of most grains, is a non-crystalline structure consisting of both linear and branched chains made up of glucose units, held together by α-glycosidic bonds. Since it is amorphous, starch is readily hydrolyzed.

As emphasized in Table 4-1, the structure of hardwood is characterized by more lignin, more acetyl groups, and less hemicellulose. This makes hardwood sample more difficult to hydrolyze than a grass. The Biofuels Program is focusing on fast growth and production of high-cellulosic and high-hemicellulosic-content feedstocks with low acetyl, uronic acid, ash and lignin content for selective conversion of biomass to ethanol.

4.4 Technical Goals that Drive Biomass-to-Ethanol Conversion Technology R&D Activities

The Ethanol Program has established a set of ethanol production cost goals and strategic objectives that drive the research and technology development activities, and are related to the performance measures listed below (in the Box) for biomass-to-ethanol conversion technology activities. National program goals include:

- In collaboration with industry partners, commercial demonstration scale production of ethanol from low-cost biomass-derived wastes and residues by year 2000 at $1.13/gallon.

[18] Tshiteya, R.M. *"Conversion Technologies: Biomass to Ethanol. Alcohol Fuels Reference Work #3"*. Prepared for the Biofuels Systems Division, Office of Transportation Technologies, U.S. DOE through the National Renewable Energy Laboratory, Golden, CO, September 1992.

- In collaboration with industry partners, commercial demonstration scale production of ethanol from switchgrass/wastes by 2005 at $0.95/gallon.
- In the long-term, commercial production of ethanol from perennial biomass crops and low value feedstocks by 2010 at $0.72 per gallon

Strategic objectives to achieve national program goals include:

- Partner with industry for near term demonstration and deployment in niche markets

- Conduct R&D in advanced technology areas to ensure potential cost reductions for next generation technologies

4.5 Rationale and Assumptions

The National Plan for Biomass Ethanol is based on assumption of level funding for the foreseeable future. The schedule includes linkages among all major elements of the program, including: Feedstock Development, Biomass Conversion Technology Research and Development, Partnership Development and Commercial Deployment. Research and development activities on the biomass conversion technology are conducted by the Program through Bench scale integrated testing. Pilot scale testing of the technology is then the responsibility of a partnership-driven effort. The final choice of feedstocks and technology to be tested at the pilot scale will be determined by the needs of the industrial partner, based on business plans developed prior to pilot scale tests. The plan assumes that core technology for conversion of biomass to ethanol developed under the Biofuels Program will be available to partners. This technology will be one of a number of options that a partner can consider, including technology developed elsewhere. Likewise, the plan assumes that the Alternative Fuels User Facility at the National Renewable Energy Laboratory will be available for use by industry partners, if desired.

4.6 Core Technology Development for Year 2000 Goal

4.6.1 Year 2000 Conversion Technology Goal

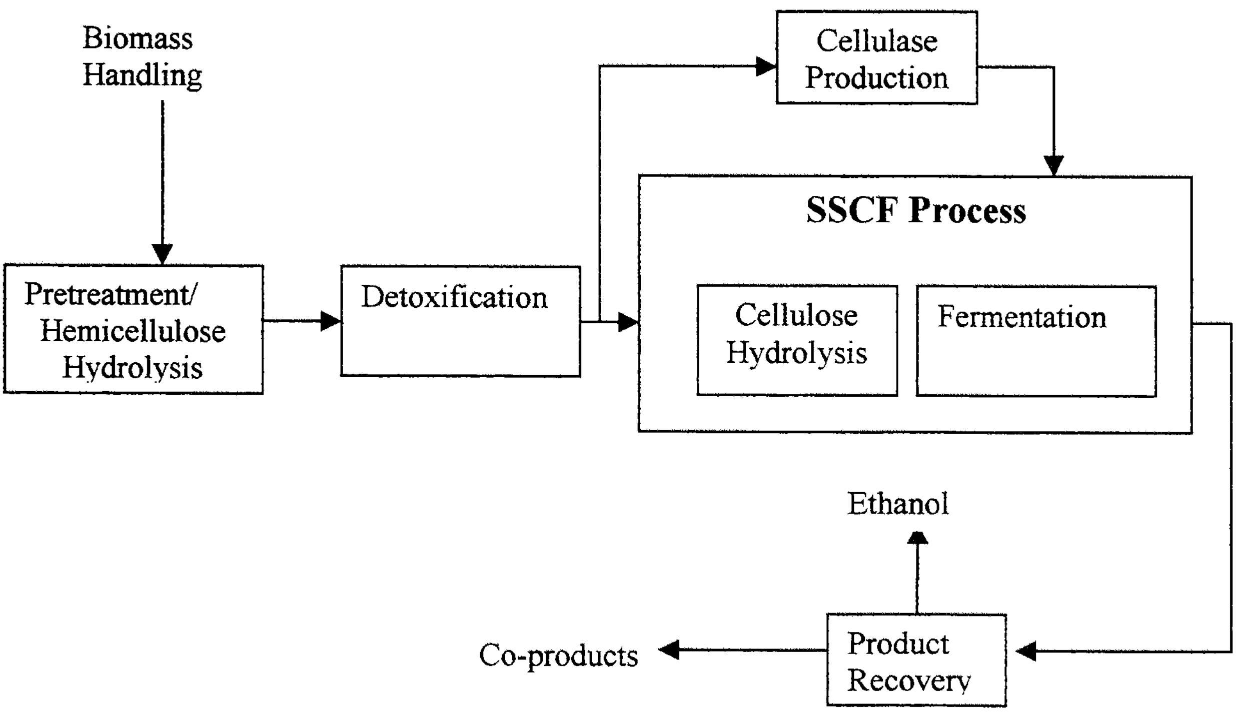
The year 2000 goal is to demonstrate, in collaboration with industry, technologies that can produce ethanol from low cost cellulosic waste materials at a cost of $1.13 per gallon (1997 dollars), assuming that we have access to a waste feedstock that costs no more than $15 per dry ton[19]. This goal applies to greenfield facilities. However, most of the projects presently being considered are retrofits of existing facilities or add-on to the existing biomass power facilities. These options have the potential to significantly lower the capital investment and ethanol production cost in the range of 70 to 90 cents per gallon.

[19] John Sheehan. *Multi-Year Technical Plan for Ethanol. March 1997 Draft.* National Renewable Energy Laboratory, Golden, Colorado.

4.6.2 Year 2000 Core Technology Development

The goal of this effort is to utilize all available information and technology to develop an integrated bioethanol process technology that supports commercialization of bioethanol and the reduction of bioethanol manufacturing cost. This support may be provided directly to bioethanol industry partners. It will culminate in the availability of an integrated process that includes pretreatment of biomass, detoxification, cellulase production, cellulose hydrolysis and fermentation of sugars to ethanol and ethanol product recovery, as shown in Figure 4-1. These process steps comprise what we refer to as the core conversion technology for the Biofuels Program.

Figure 4-1. Simplified Diagram of Year 2000 Core Technology Development for Biomass Conversion



The feedstock handling activity includes size reduction (to open up the complex structure and to expose the carbohydrates), as well as the design of efficient pretreatment to render the feedstock more susceptible to the subsequent conversion steps. The pretreatment uses dilute acid to prehydrolyze the hemicellulose fraction of the biomass, while rendering the cellulose fraction more susceptible to further hydrolysis with enzymes. Prehydrolysis can lead to production of acetic acid, sulfuric acid and other unwanted byproducts that are toxic to the organisms used to ferment the sugars to ethanol. Detoxification involves process steps such as ion exchange or overliming to remove these unwanted components. A portion of the pretreated and detoxified biomass is then sent to a fungal fermentation where cellulase enzymes are produced. These enzymes are capable of hydrolyzing the intact cellulose to its components sugars. The cellulase enzyme is then fed into the fermentation vessels, where simultaneous hydrolysis and fermentation to ethanol occurs. Hydrolysis rate is enhanced because of the removal of sugars by the fermentative organism. The fermentation step relies on an organism that can ferment both xylose and glucose sugars. Recovery of the alcohol and the residual lignin in the biomass result in lignin burned for steam and electricity production and a fuel grade distilled ethanol product.

4.6.3 Year 2000 Technology Options under Investigation

Table 4-2. Biomass-to-Ethanol Technology Options and Major Players

Type of Technology	Representative Organizations
Concentrated Acid Technology	• ARKENOL, Mission Viejo, CA • MASSADA RESOURCE GROUP, Birmingham, AL
Dilute Acid Technology	HFTA, Oackland, CA
Pretreatment/Enzyme Technology	• BC International, Dedham, MA • SWAN BIOMASS, Illinois • WEIS, Palo Alto, CA • National Renewable Energy Laboratory

A number of processes are being studied for conversion of cellulosic biomass into ethanol. The main difference between them relies on the choice of the catalyst used to break the complex structure of cellulose and hemicellulose into simple fermentable sugars. This catalyst could be an acid (acid hydrolysis) or an enzyme (enzymatic hydrolysis). In collaboration with industry partners, the Biofuels Program supports R&D activities in both acid and enzymatic hydrolyses. Table 4-2 shows major biomass-to-ethanol technology options currently being considered by the Program, as well as the names of industry partners and national laboratories involved in these R&D activities.

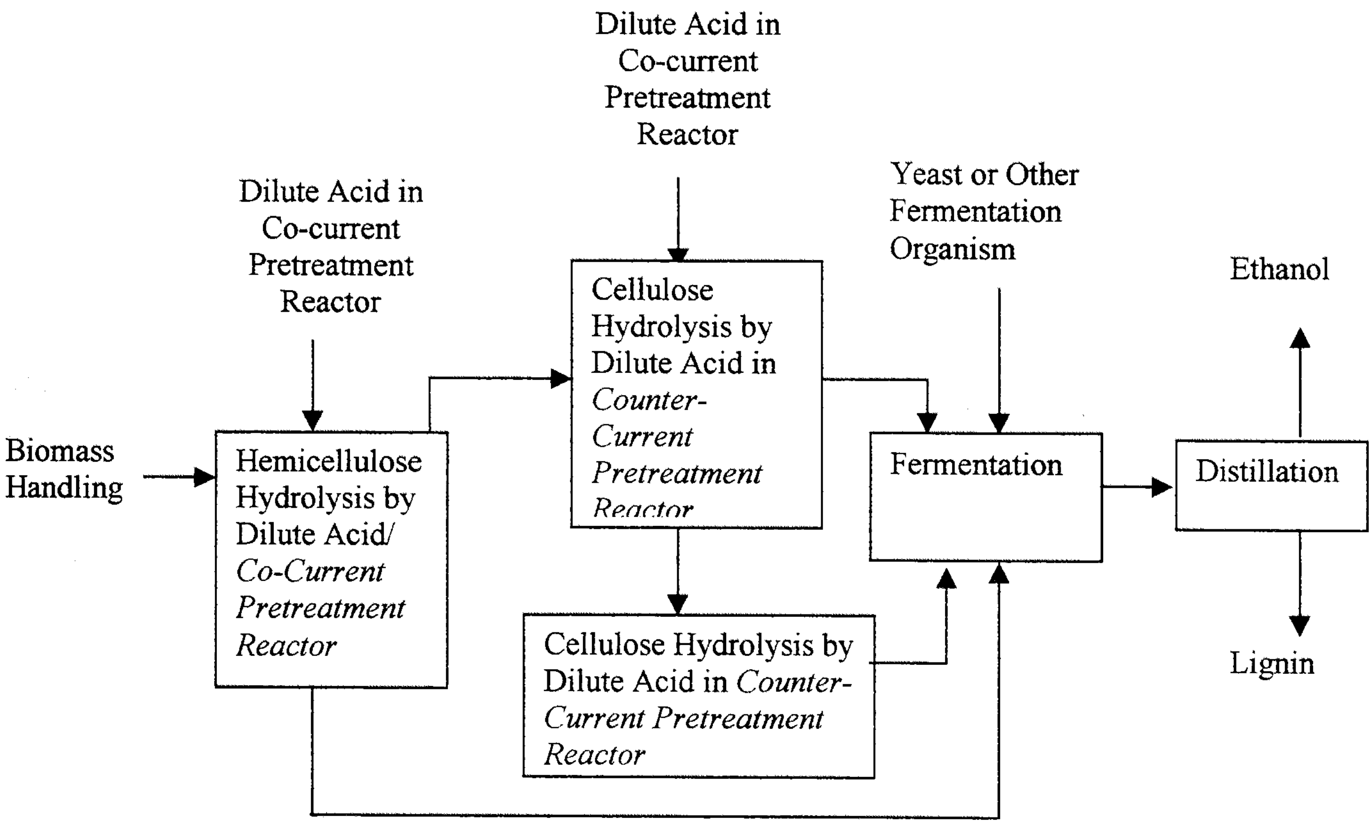
4.6.3.1 Dilute Acid Technology Option

Acid hydrolysis of cellulosic biomass has been studied and practiced commercially for many years. Several types of acids, including sulfurous, sulfuric, hydrochloric, hydrofluoric, phosphoric, nitric, and formic have been used for acid hydrolysis. Several dilute acid hydrolysis pilot plants were constructed in the United States during war time as part of an effort to produce ethanol for fuel use but, at the end of the wars, they were shut down because of their inability to compete with cheap petroleum products[20]. Thus, acid-catalyzed processes provide a near-term technology for conversion of cellulosic biomass to ethanol. However, more research is needed to improve the low yields of 50% to 70% typical of dilute acid systems. Figure 4-2 shows a

[20] Wenzel, H.F. 1970. *The Chemical Technology of Wood.* New York: Academic Press.

simplified flow diagram of a typical dilute acid hydrolysis process currently under investigation by the Biofuels Program for the conversion of softwoods.

Figure 4-2. Simplified Flow Diagram of the Three Stage Counter-Current Dilute Acid (Non-Enzymatic) Hydrolysis for the Conversion of Biomass to Ethanol

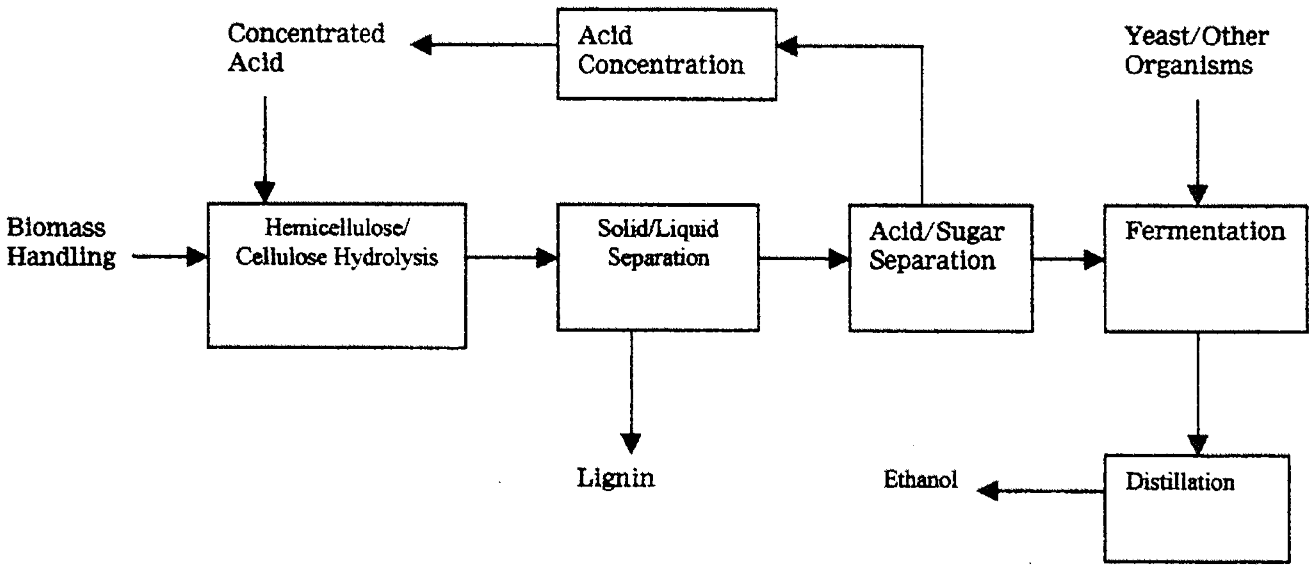


This is a three-stage process. In the first phase, the hemicellulose is hydrolyzed with dilute acid in a co-current pretreatment reactor. In the second phase, the unreacted cellulose material from the first phase is hydrolyzed with dilute acid in a counter-current reactor. Finally, the residue from the second phase is reacted with dilute acid in a second counter-current reactor. The Biofuels Program is paying a special attention to this process because this option offers the most promising potential for total elimination of the requirement for expensive enzymes.

4.6.3.2 Concentrated Acid Technology Option

Concentrated acid options achieve the desired high yields. However, these options require the use of either large amounts of low-cost acids (e.g., sulfuric) or the use of more potent but expensive acids (e.g., hydrochloric). In either case, the recycle of concentrated acid by an efficient, low-cost recovery operation is required in order to achieve an economic operation. R&D activities are underway to design and develop an efficient and low-cost concentrated acid recovery system. Figure 4-3 shows the flow diagram of the concentrated acid technology currently under consideration by the Biofuels Program in collaboration with Arkenol (of Mission Viejo, CA) and Massada Resource Group (of Birmingham, AL).

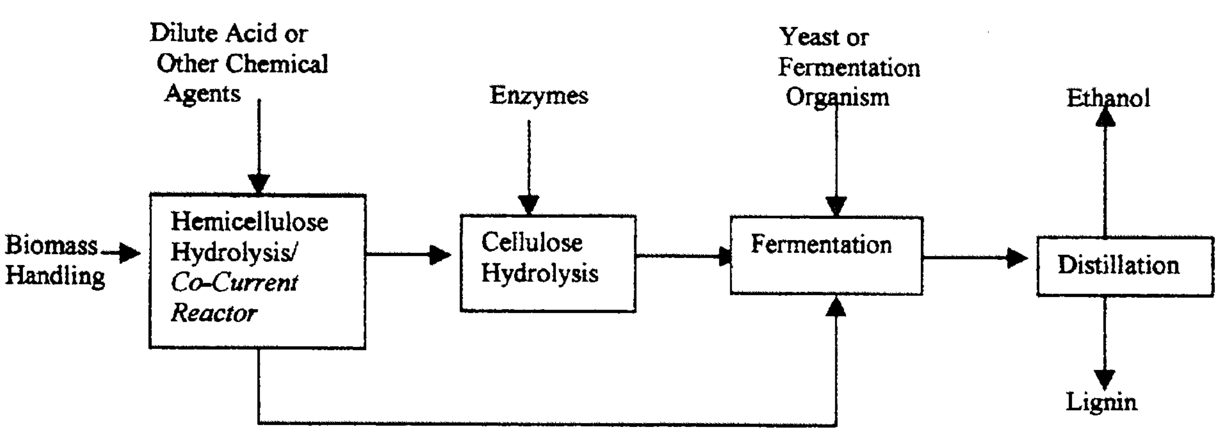
Figure 4-3. Concentrated Acid Technology for Biomass Conversion to Ethanol



4.6.4 Co-Current Pretreatment & Enzymatic Hydrolysis

This is a two-stage hydrolysis process. In the first step, the hemicellulose is hydrolyzed with dilute acid in a co-current reactor. The unreacted cellulose from the first stage is then hydrolyzed in an enzymatic reactor.

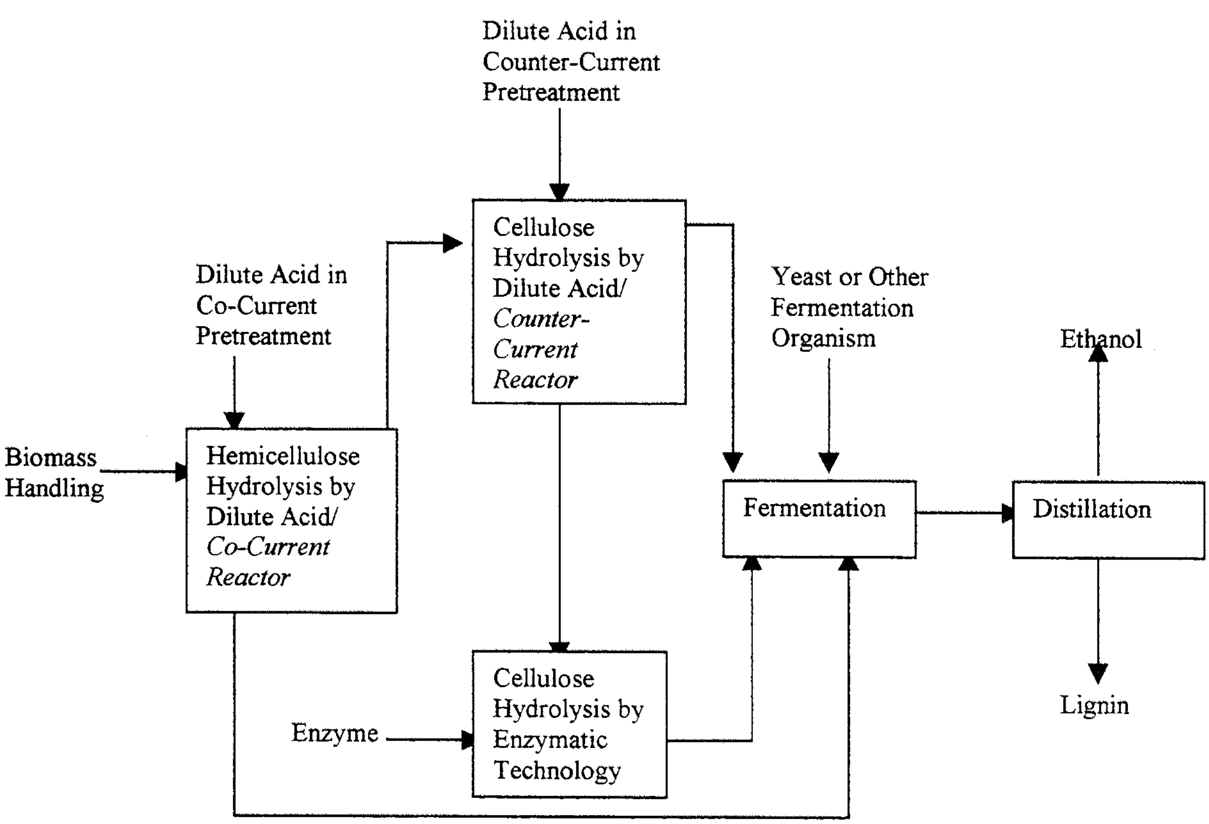
Figure 4-4. Simplified Diagram of the Co-Current Pretreatment & Enzymatic Hydrolysis for Conversion of Biomass to Ethanol



4.6.5 Counter-Current Dilute Acid Pretreatment & Enzymatic Hydrolysis

This is a three-stage process. In the first phase, the hemicellulose is hydrolyzed by dilute acid in a co-current pretreatment reactor. In the second phase, the unreacted cellulose material from first stage is further hydrolyzed by dilute acid in a counter-current pretreatment reactor. After this second stage of pretreatment, a large fraction of cellulose is hydrolyzed, leaving only a small portion of unreacted cellulose that is sent to an enzymatic hydrolysis reactor. Since only a small portion of cellulose (unreacted residue) is sent to the enzymatic hydrolysis reactor, the size of the enzymatic reactor as well as the amount of required enzyme will be much smaller than if the dilute acid counter-current step was not included in the system. Therefore, this process has the potential to be considered as one of the strategies to reduce the cost of producing ethanol from cellulosic biomass.

Figure 4-5. Simplified Flow Diagram of the Two-Stage Counter-Current Dilute Acid Pretreatment & Enzymatic Hydrolysis for the Conversion of Biomass to Ethanol



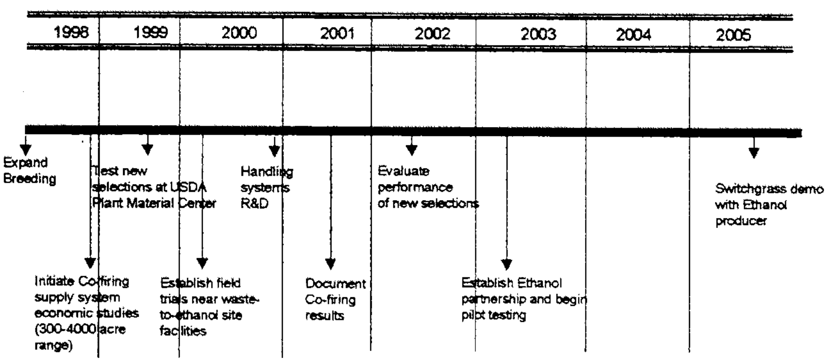
4.7 Mid-Term Core Technology Development: Ethanol from Switchgrass

Utilizing the latest biotechnology techniques in collaboration with industry, the goal in the year

2005 is to commercialize conversion technology allowing the use of switchgrass energy crops and low value feedstocks. The improved technology will allow for ethanol to cost no more than \$0.85 per gallon when produced from energy crops and low value feedstocks in 2005.

Switchgrass research and development needs to proceed simultaneously in four to five regions of the U.S. in order to insure that the developing cellulosic ethanol industry will have adequate flexibility in choosing suitable locations. The five regions include the North Central region, the Northeastern region, the Northeast/Lake region, the South Central region, the Southeast region and the Mid-Atlantic region. At least one fully integrated crop development center is desirable for each region. The metrics of major strategic objectives to achieve the Year 2005 Goal are shown in Figure 4-6.

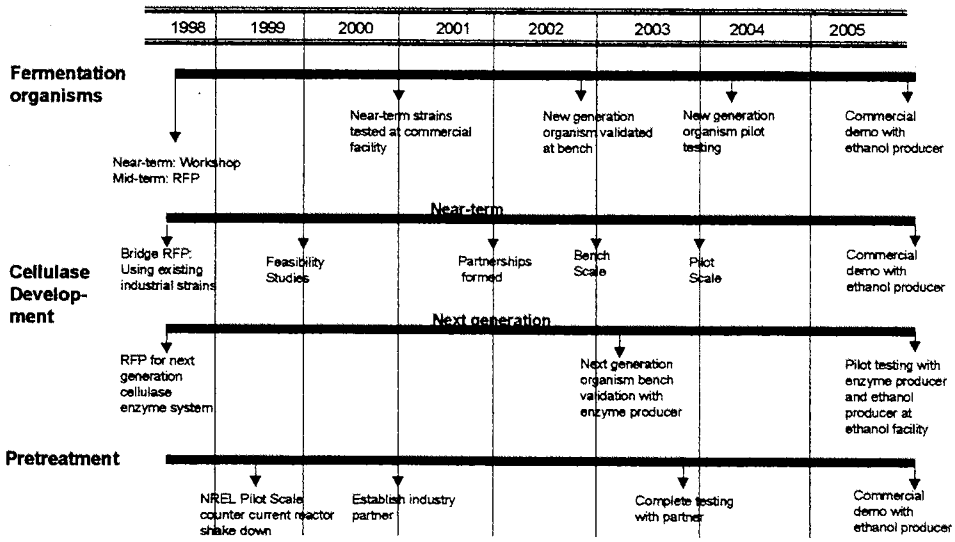
Figure 4-6. Ethanol from the Bioenergy Crop Switchgrass



4.8 Long-Term Core Technology Development

Long-term goals are to produce ethanol from perennial biomass crops and low value feedstocks by 2020 at \$0.78 per gallon (U.S. average), and \$0.60 per gallon for a plant with the latest technology and low cost feedstocks. The rapidly evolving biotechnology field offers opportunities to reduce the cost of biomass ethanol. OFD is working with industry and NREL to roadmap the development of technologies that will substantially reduce the cost of ethanol conversion.

Figure 4-7. Core Ethanol Production R&D



The key change in process performance overall in the mid-term deployment of bioethanol technology is that it will be able to accommodate a dedicated energy crop, especially switchgrass, as a feedstock. This means that process improvements must be achieved to offset the increase in feedstock cost from $15 per dry ton for waste feedstocks to $37 per dry ton of switchgrass in 2005. Several options are available to achieve this goal, including: reduction in the amount and cost of cellulase enzyme to be used in the process, improvement of cellulase enzyme activity, development of improved fermentation organism, countercurrent pretreatment, as shown in Figure 4-7. The focus is not on near term technologies that are being perfected by industry, but rather, attempting "next generation" breakthroughs. Major specific R&D activities are described below.

4.8.1 Advanced Fermentation Organisms R&D

During FY 1997 and FY 1998, OFD researchers focused their efforts on the development of advanced fermentation organisms that will improve the efficiency of converting biomass to ethanol. One strategy is to look at genetically engineered *Lactobacillus*. This organism is hardy, tolerating more severe conditions of pH and temperature than *Zymomonas*. These robust biocatalysts have the potential to achieve an efficient simultaneous co-fermentation of a variety of mixed sugars including glucose, mannose, galactose, cellobiose, xylose, arabinose. Because of the potential to co-ferment a large variety of feedstocks, the R&D on recombinant *Lactobacillus* promises many significant benefits to the Program, including an increase in the productivity; an increase in ethanol yield, output and revenue; a reduction in capital and operational costs. Significant potential in this area is anticipated in the development of a *Zymomonas Mobilis* with enhanced capabilities. In FY 1999, researchers will continue work on advanced fermentation organisms that are capable of operating on mixed sugars from waste feedstocks and switchgrass. OFD anticipates expenditures of $2 million in each of the next three fiscal years as researchers strive for fermentation advances.

4.8.2 Advanced Cellulases R&D

Commercially available cellulases are expensive. In FY 1998, work was continued on developing advanced engineered cellulases and expression systems. The program funds leading edge biotechnology techniques for improvement of the specific activity of cellulase enzymes. OFD has set a goal of establishing one partnership with a cellulase producer in FY 1998. The objective of the partnership will be to develop highly productive, low-cost cellulase systems. In FY 1999, OFD intends to continue research and development in this area by completing a conceptual design of an on-site cellulase production technology and initiate demonstrations of on- site cellulase technology. Expenditures in FY 1997 was around $2.1 million with increased funding to $2.5 million in FY 1998 and $5.0 million in FY 1999.

4.8.3 Improved Pretreatment R&D

A cornerstone in the plan to make biomass ethanol available on a commercial scale is the work being done in the area of pretreatment technologies. The fundamental basis of this approach is rooted in the observation that the hydrolysis of xylan, the major hemicellulose component in most biomass feedstocks, is biphasic, with an easy-to-hydrolyze and a hard-to-hydrolyze fraction. Kinetic modeling has demonstrated that a two stage countercurrent reactor in which each stage is operated at different temperatures is the best design for achieving high yields of xylose sugars. This would allow us to minimize or even eliminate the use of cellulase enzymes, which represent a major cost component in bioethanol production. FY 1998 brought efforts to incorporate and modify NREL's Process Development Unit (PDU) to include the advanced pretreatment reactor. During FY 1999, OFD will conduct bench scale testing of cost-effective pretreatment technologies for softwood feedstocks and potential co-products of softwood to improve process economics. Researchers will also complete modifications and initiate testing of a countercurrent pretreatment reactor. These efforts are expected to cost $2.0 million in both FY 1997 and FY 1998. In FY 1999, funding is expected to jump to $5.0 million.

4.8.4 Integrated Process Development

In the area of integrated process development, OFD is conducting a number of bench-scale studies during FY 1997-FY1998. Researchers will focus on evaluating and optimizing operations and will include studies in areas such as detoxification as a means toward improving the overall process. In FY 1998, OFD will seek to validate the bench scale performance of a genetically improved fermentation organism that is capable of fermenting available sugars. During FY 1999, researchers will continue work on integrated bench-scale studies in order to evaluate overall process performance. In addition, they will conduct testing of softwood thinnings from private and public forest, including National Forests, in cooperation with industrial partners.

4.8.5 Process Development Unit (PDU)

The operation of the PDU is vital to successful commercialization of the biomass-to-ethanol technologies. It verifies process performance, and generates performance and scale-up data necessary to design large-scale commercial facilities. In conjunction with the above mentioned research in integrated processes, OFD will continue to operate the NREL process development unit (PDU) in a fully integrated mode (feedstock to ethanol) with one or more partners over the FY 1997-FY1999 time frame. Researchers will test all unit operations including handling, pretreatment, and fermentation to evaluate process efficiency and costs for agricultural waste feedstocks. The expected level of funding in this area will be \$8.5 million in FY 1997; \$8.7 million in FY 1998; and, \$11. 0 million in FY 1999.

4.8.6 Lignin Conversion to High Value By-products

The Program believes that the conversion of lignin to high value byproducts has the potential to favorably impact the overall cost of biomass-to-ethanol process. Lignin (15-30 weight% of lignocellulosics) is available as a residue of carbohydrate to ethanol conversion. The lignin left over after the fermentation process represents a significant fraction of the feedstock. An ethanol plant producing 50 million gallons/year of ethanol would consume almost 2000 tpd of biomass and have about 500 tpd of lignin as a byproduct. Since feedstock costs represent the largest portion of bioethanol production costs, R&D effort is underway to identify byproduct opportunities for this material. For the Year 2000 bioethanol process, lignin is planned to be burned to recover its fuel value and generate steam or electricity for the plant. This approach represents a serious under-utilization of lignin. In the Year 2005 bioethanol process, as more costly dedicated feedstocks will begin to be used, the conversion of at least a fraction of the residual lignin into high-value coproducts has the potential to offset some of the higher cost of he feedstocks and thus improve the overall economics of the bioethanol process.

4.8.7 Syngas fermentation Process

The objective of this program is to develop technology for the conversion of liquid and solid corn processing wastes to ethanol. The conversion of solid wastes through gasification/fermentation has the potential to significantly reduce the costs for biomass conversion to ethanol through improved rates and conversion efficiencies. The project is conducted at ORNL using Bioengineering Resources, Inc. technology and Batelle oxygen blown gasifier, producing a gas containing 38.3% H_2, 41.7% CO, 17.1% CO_2, 2.8% CH_4 and 0.1% N_2. Other capital equipment includes solids handling equipment (shredder and dryer, as needed), gas treatment, bioreactor, distillation, ethanol dehydration and auxiliaries. A 20% contingency is included. A basis of \$1.30/gal ethanol is assumed. The project is managed by ORNL. The syngas for ethanol production requires high CO and H_2 content to maximize yields. Therefore, modification of the basic design conditions may be necessary to produce a gas rich in CO and H_2. BRI has isolated proprietary bacteria which convert CO, CO_2 and H_2 to ethanol according to the reaction scheme:

$$6\,CO + 3\,H_2O \dashrightarrow C_2H_5OH + 3\,H_2O$$

$$6\,H_2 + 2\,CO_2 \dashrightarrow C_2H_5OH + 3\,H_2O$$

About 20 - 25 g/l ethanol are produced in a continuous stirred tank reactor (CSTR).

4.9 Program Milestones

Table 5-3. Biomass-to-Ethanol Conversion Program Milestones

YEAR	PLANNED ACTIVITIES
1998	Complete confirmation of feasibility for dilute acid cellulose hydrolysis process for converting Softwoods to ethanol
	Complete bench-scale testing for countercurrent pretreatment reactor concept
1999	Complete solicitation and placement of contracts for industry co-sponsored ethanol strain Development projects
	Collaborate with BCI in the development of enzymatic conversion technology for the conversion of rice straw to ethanol for the Gridley project
	Complete installation and shakedown test of minimum engineering scale counter-current pretreatment reactor designed for confirmation of feasibility
	Begin development phase for dilute acid conversion of softwoods with an industrial partner
	Select fermentation host microorganism capable of meeting second generation ethanol producing strain goals
2000	Confirm feasibility for the countercurrent pretreatment reactor process utilizing the minimum Scale engineering reactor
	Start up first ethanol production facility converting agricultural coproducts to ethanol
2001	Collaborate with industry partner to move countercurrent pretreatment reactor towards Commercialization
	Complete development of enzymatic conversion technology in support of industrial partner
	Complete development phase (pilot-scale/engineering guarantee R&D) for conversion of softwood residues to ethanol and electricity
	Increase cellulase enzyme specific activity by a factor of two relative to *T. reseei* enzymes
2002	Industry partner to begin construction of plant for converting rice straw to ethanol and Electricity
	Start up commercial production of ethanol from municipal solid wastes
	Begin work on enzymatic conversion of corn stover to ethanol with an industry partner
	Complete development of new fermentation microorganism
2003	Start up commercial conversion of softwood residues to ethanol and electricity
	Complete confirmation of feasibility for enzymatic conversion of corn stover to ethanol and move into development phase with industry partner
	Enzyme companies begin marketing cost-competitive enzymes and/or enzyme technology needed for biomass conversion to ethanol

5 STRATEGIES TO REDUCE ETHANOL PRODUCTION COST

STRATEGIES FOR ETHANOL COST REDUCTION

Enzymatic processes for the conversion of biomass feedstocks to ethanol have the potential to achieve substantial cost reductions if adequate level of funding is available to support R&D activities focusing on the specific areas mentioned below:

- Improving fermentation microorganism
- Improving cellulase specific activity
- Developing genetically engineered biomass feedstocks with higher carbohydrate content
- Development of countercurrent pretreatment technology
- Lignin conversion to high value fuels and fuel additives
- Improving ethanol conversion yield to 95% of theoretical

Enzymatic conversion processes offer opportunities for substantial cost reductions. This is because enzymes offer the opportunity to hydrolyze the biomass under very mild conditions with very high yield of sugars from the biomass carbohydrates. This eliminates the high pressure and temperatures as well as the high acid concentrations and acid recycling processes required for acid hydrolysis technologies. Lower cellulase enzyme costs, higher temperature-resistant fermentation microorganisms, and higher carbohydrate content feedstocks have all been identified as opportunities to substantially reduce the cost of ethanol production from biomass in an enzymatic conversion process. Recent developments in biotechnology point to an increased probability of success[21].

Specific improvement targets have been identified to reduce the cost of ethanol from biomass by approximately 50 cents per gallon in the mid term. A 3-fold increase of the cellulase specific activity is targeted for 2005 and a 10-fold increase is targeted for 2012. Substantial improvements are also targeted for the ethanol fermentation microorganism. The improved fermentation microorganism must convert biomass sugars at a temperature of 55C, in hydrolysate conditioned only by overliming, with all monomeric hexoses and pentoses converted to ethanol, using nutrients costing less than 5 cents per gallon at a final ethanol concentration of 5%. The efficiency of the ethanol producing microorganism is also targeted. Improving the yield of ethanol to 95% of theoretical yield will reduce the cost of ethanol production. A further reduction in ethanol cost can be achieved if the carbohydrate composition of the biomass can be increased by 20%. The combined improvements that are mentioned in this section will reduce the cost of ethanol by approximately 50 cents per gallon[22].

[21] *Ethanol Conversion Technology*. The rationale of priorities surrounding R&D activities at NREL. Information provided by David Glassner, Manager, the Biofuels Program at NREL. August 1998.

[22] Ibid.

In view of the continuing advances in biotechnology, substantial progress toward the cost reduction target described above is likely in the next 5 years. Within 15 years we expect to see all or most of the performance enhancements described above accomplished if resources are focussed on achieving the goals. Some of the biotechnology tools that will be important to reaching the goals are discussed next. First, the continuing evolution of protein engineering know-how and metabolic engineering make these 'old' tools even more predictable and useful for the future. Relatively new techniques such as directed evolution and gene shuffling will be invaluable, considering their spectacular successes to date in related endeavors. Plant biotechnology continues to advance and its use for improving plant characteristics offers additional cost reduction potential. Genetic manipulation of plants to alter the carbohydrate/lignin ratio seems to be feasible. In summary the 'old' tools of metabolic engineering and protein engineering combined with newer techniques such as gene shuffling, directed evolution, and plant biotechnology, can help reduce the cost of ethanol significantly. It is likely that new tools and techniques will be available in the near future.

6 NEAR-TERM COMMERCIALIZATION OF BIOMASS ETHANOL TECHNOLOGIES

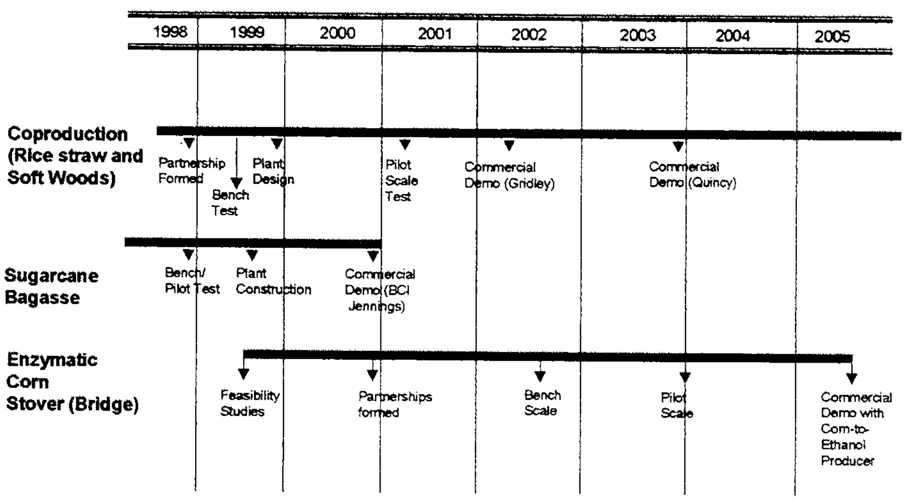
The Office of Fuels Development's strategy is to foster the development of technology through cost sharing with partners from private industry for commercialization of new technology through Cooperative Research and Development Agreements and contracts. The partners who are the furthest along have targeted specific feedstocks, have obtained supply contracts for all or a substantial portion of the feedstocks needed for their prospective production plants, have chosen sites for plants, and are in various stages of obtaining financing. Partners in this stage include BCI, Arkenol, and Masada Resources Group.

The next level of partners would be capable of cost sharing the development of technology and/or the assessment of business opportunities. Currently NREL is exploring or has entered into collaborations with a number of entities associated with the corn ethanol industry, biomass power industry, and others, including the Corn Refiners Association, National Corn Growers Association, Ogden Pacific Power, Collins Pine, Wheelabrator-Martell and Sealaska Native Corp.

Acid hydrolysis technologies offer the best opportunities for near term commercialization of biomass to ethanol technology. The collaborations with the BCI Jennings plant, Arkenol, and Masada Resources Group are aimed at commercializing acid hydrolysis technology. Either concentrated or dilute acid is utilized to hydrolyze the hemi-cellulose and cellulose to pentose and hexose sugars. This technology is relatively simple and basic versions have been studied for several decades. The pioneer plants which choose to use this technology may find that lending institutions and investors may accept the technology fairly readily. Supported by OFD in collaboration with industry and NREL, BCI is working to pull together enzymatic process technology for the project in Gridley, CA, involving rice straw. In Canada, Iogen and PetroCanada collaborate on building an enzymatic conversion demonstration plant in Ottawa, Canada. While less simple than acid hydrolysis, enzymatic conversion technology offers increased opportunities to reduce the cost of biomass conversion technology in the mid term with modern biotechnology techniques. OFD is supporting the development of this enhanced technology in partnership with industry, universities, private research laboratories, and the national laboratories.

A number of facilities are currently in various stages of production. These commercial demonstration plants are highly leveraged industry driven partnerships. Each of these facilities is being financed with an 80 percent or higher private sector investment and a 20 percent or less DOE cost-share. These partnerships are instrumental in achieving the Biofuels Program's programmatic goals. Major near-term R&D projects, co-funded by DOE and its industry partners, are described below. The metrics for major near-term activities are shown in Figure 6-1.

Figure 6-1. Wastes-to-Ethanol



6.1 The BC International Project in Jennings, LA

In 1997, OFD established a waste-to-ethanol facility partnership with BC International (BCI) using sugarcane bagasse as feedstock. B.C. International plans to break ground in 1998 in Jennings, LA to construct a facility that will convert sugar cane bagasse to ethanol. The first phase of the project is the conversion of an idle, grain-based ethanol plant to one that will produce 10 million gallons per year ethanol from bagasse. In subsequent phases, BCI will add capabilities and additional capacity for processing other biomass wastes, including sawdust, rice straw and rice hulls. DOE's share will be $6.0 million with BCI providing a projected $34.0

million (over 80% cost-share). Schedule: the project started in June 1997 and the expected finish date is December 1999.

6.2 The Arkenol Sacramento Project

Arkenol Inc., headquartered in Mission Viejo, CA., is pursuing a rice-straw-to-ethanol facility in Sacramento, CA. The objective of this project is the commercialization of Arkenol's ethanol production technology (concentrated acid) in Sacramento, California for the co-production of ethanol and electricity. The scope of the work includes site permitting activities, feedstock supply contracting, and obtaining an Engineering Procurement and Construction contract. For this project, rice straw is the major feedstock under consideration. The project is managed by DOE Office of Fuels Development (OFD). The budget participation from the DOE Office of Fuels Development amounts to $4 million; the total project cost is estimated at over $100 million. Schedule: the project started in March 1998 and the expected finish date is March 2000.

6.3 Masada Resources Group NY Project

Masada Resources Group, Inc., headquartered outside of Birmingham, AL, is planning a municipal solid waste-to-ethanol facility in Orange County, New York. The project will build a 6 million gallon/year ethanol plant at a waste sorting plant in Middletown, New York. The technology deployed will be the concentrated sulfuric acid technology developed at TVA. Masada has entered a subcontract with NREL to resolve process issues including equipment sizing, feed systems, optimize process parameters, and establish vendor and EPC guarantees. The project will be managed by NREL. Budget: NREL budget participation amounts to $499K; the total project cost is estimated at over $100 million. Schedule: Masada expects to break ground next summer and start commercial operation a year later.

6.4 The Gridley Project

The objective of this project is to commercialize rice straw-to-ethanol and electricity technology in the Gridley, CA area. BC International, headquartered in Dedham, MA will replace SWAN BIOMASS as the project owner/operator. Commitments for rice straw, urban green waste and softwood feedstocks are currently being pursued. A proposal to revise the phase II scope of work was expected from the SWEC and its lower-tier partners by the end of January 1998. The project will be managed by NREL. Budget: NREL budget participation amounts to $1,650,000, while participation from others amounts to $633,000. Schedule: Phase I started February 1996 and finished March 1997. Phase II started April and is estimated to end in April 1999.

6.5 The Conversion of Softwoods to Ethanol: the Quincy Library Group (QLG)

The objective is to evaluate the preliminary technical and economic feasibility of dilute-acid pretreatment methods for converting softwood forest thinnings to ethanol, and to identify major technical hurdles. The high lignin content of softwoods, coupled with the strong lignin-carbohydrate matrix make softwoods more difficult to convert than hardwoods. This project is examining the economic, environmental and regulatory feasibility of siting one or more Forest

Biomass to Ethanol manufacturing facilities in Northeastern California. The study site includes most of the Lassen and Plumas National Forests and the Sierraville Ranger District of the Tahoe National Forest. The Quincy Library Group has put forth a plan to strategically thin the forests so as to reduce fire danger, improve forest health, and restore ecosystem balance. The study will identify and evaluate several sites in the study area which have the greatest potential for long-term operation of a financially attractive biomass-to-ethanol production facility. The effort will evaluate biomass supply as well as ethanol and power generation market issues which could impact the longer-term viability of the facilities.

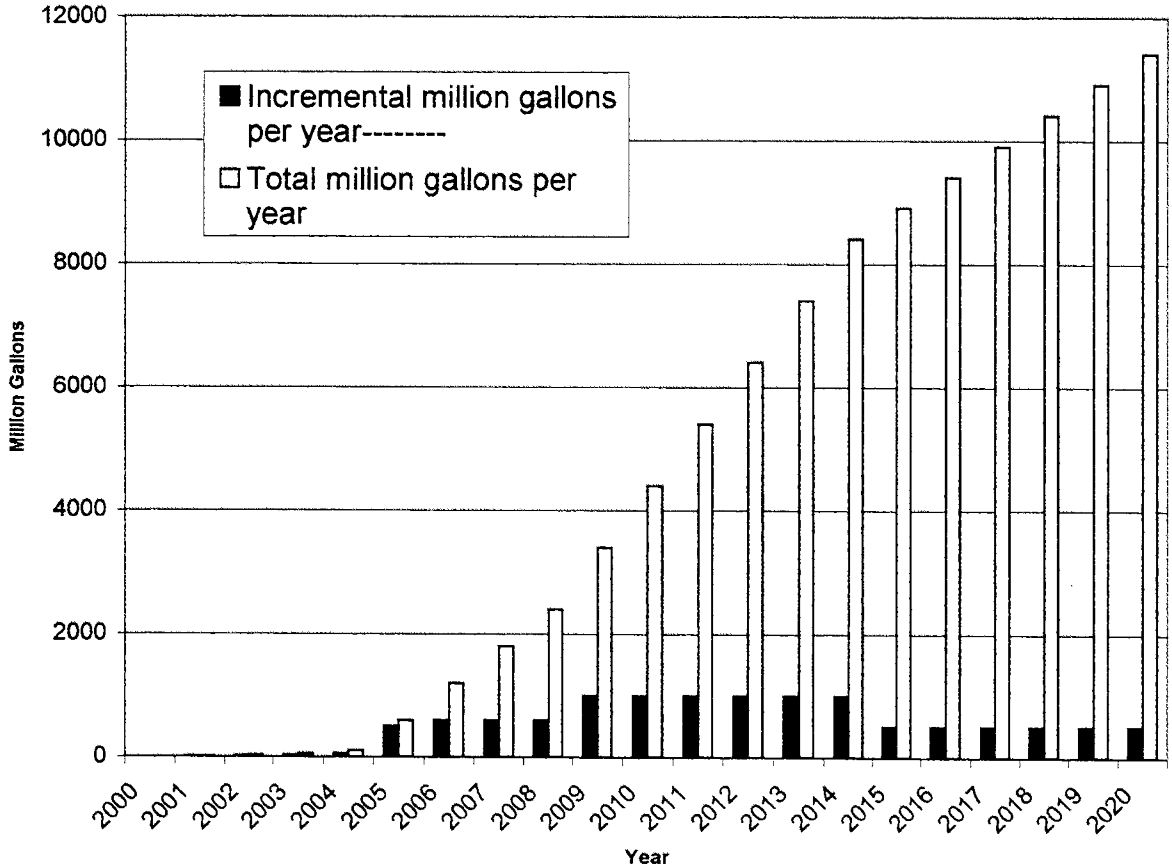
6.6 Bridge to Corn Ethanol Industry: Enzymatic Conversion of Corn Stover:

The Office of Fuels Development (OFD) wants to add committed and capable partners to help improve technology development and commercialization. OFD has targeted the corn processing industry which has the capacity to produce 1.6 billion gallons per year. Furthermore, they can have access to nearly 200 million tons per year of corn stover which is residues left in the field after harvesting. OFD is soliciting these companies to evaluate the business opportunity that corn stover offers. While short term commercialization is not expected, partnerships with the corn processing industry will bring their suppliers, the enzyme companies, into the development of more cost effective cellulase enzymes needed for producing ethanol from biomass. Collecting and converting 40% of the available corn stover could produce over 10 billion gallons of ethanol per year. The corn processing industry's financial resources, existing plant infrastructure, large scale processing know-how, and knowledge of the ethanol markets are ingredients necessary for a successful deployment beyond pioneer plants.

7 PROJECTION OF BIOMASS ETHANOL MARKET PENETRATION

By 2004, at least three ethanol plants will be in operation, using biomass wastes, and a partnership with the corn ethanol industry will complete pilot-scale work on ethanol production from corn stover. Masada Resources' first plant is assumed to start up in 2001, and BCI/Jennings plant is assumed to start in 2002; Arkenol's first plant is supposed to start in 2003; Griedley/BCI's plant and another potential plant are expected to start in 2004; Quincy Library Group's softwoods plant and corn fiber add-ons to corn ethanol plants are expected in 2005; Masada's and BCI's new plants are expected in 2006; corn fiber, stover, and softwoods plants are expected to start around 2007; etc. Switchgrass development activities will reach a point which enables the addition of this crop to the waste feedstock base of an ethanol plant by 2005.

Figure 7-1. Projection of Biomass Ethanol Market Penetration



If the budget is available at 100% level, the cellulosic ethanol market goals (in million gallons per year) for FY2000 are shown in Figure 7-1. The biomass ethanol market is expected to grow from 600 million gallons in 2005 to 4 billion gallons in 2010, and up to 11 billion gallons in 2020. These projections[23] show that the growth of cellulosic ethanol is reduced by 2015 because the blend market is saturated in view of RVP constraints and other factors analyzed by our refinery model. If neat ethanol takes off, we can show a higher growth rate for the outyears.

Ethanol can be mixed into gasoline at volumes up to at least 10 percent and be used in conventional motor vehicles (without engine modification), displacing about an equal amount of gasoline, providing the associated energy security and carbon reduction benefits. This is an important transitional market that substantially eases the difficulties of having to introduce simultaneously a new fuel and new vehicles that can use the fuel. Also, a large fraction of the

[23] *Sector Budget Decision Unit: Transportation Biofuels.* Multi-Year Information for FY2000-2004 Budget Formulation. Prepared by the U.S. DOE Office of Fuels Development (OFD), Biofuels Program. May 1998.

octane needed for today gasolines come from toxic aromatic components such as benzene, toluene, xylene and tri-methyl benzenes. By blending ethanol into gasoline, ethanol provides an alternative to these toxic octane enhancers, thus allowing significant reductions in toxic air emissions without sacrificing fuel performance. Another reason supporting the blend market is provided by current EIA projections which show that, at least for the foreseeable future, the price of petroleum is not likely to increase very much. Therefore, as long as this "cheap" oil persists in the fuel market place, the United States will find itself importing greater amounts of petroleum each year. In light of these projections, the Biofuels Program has moved away from any assumptions of catastrophic oil price jumps as a necessary condition for market penetration of ethanol in the transportation sector (though such sudden shocks are certainly possible). We have, instead, switched to a more targeted strategy that allows ethanol to gain market share as a fuel oxygenate and an octane enhancer. These markets are higher value than the straight gasoline market, as shown in Table 7-1.

Table 7-1. Estimated Consumption of Ethanol Fuel in the United States, 1992-1998 (million of Gasoline-Equivalent Gallons)[24]

Fuel	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Alt. Fuels							
E85	0.021	0.048	0.080	0.190	0.694	1.416	1.614
E95	0.85	0.80	0.140	0.995	2.699	2.628	2.628
Oxygenate Fuel Mrkt							
Gasohol	701.0	760.0	845.90	910.70	660.20	787.80	852.50
Total EthOH Mrkt	**701.871**	**760.848**	**846.12**	**911.885**	**663.593**	**791.844**	**856.742**
Traditional Fuels							
Gasoline	110,135	111,323	113,144	115,943	117,783	119,232	121,614
Diesel	23,866	24,297	27,293	28,555	30,101	30,777	37,758

Source: EIA/Alternatives to Traditional Transportation Fuels 1996.

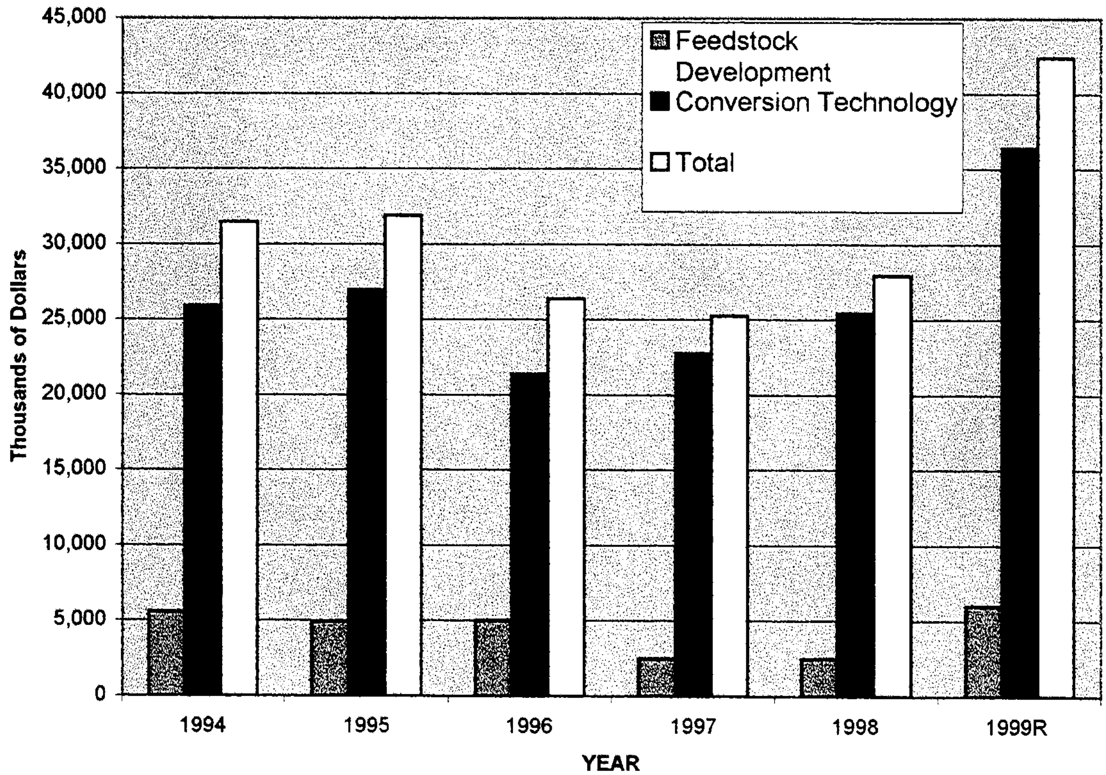
8 PROGRAM BUDGETS AND EXPECTED BENEFITS

8.1 Budget History for the National Biomass Ethanol Program

Figure 8-1 shows the budget history for the National Biomass Ethanol Program Plan over the period 1994-1998 time frame. The requested budget for FY 1999 has also been included for comparison purposes. The Figure shows a decrease from $31.5 million in FY 1994 to almost $28 million in 1998. The requested budget for FY 1999 shows a 52% increase when compared to FY 1998 budget.

[24] EIA/Alternatives to Traditional Transportation Fuels 1996.

Figure 8-1. Budget History for the National Biomass Ethanol Program Plan



8.2 Trends in Base Funding

As shown in Table 8-1 and Figure 8-2, the budget of the Ethanol Program increases from $28 million in 1998 to $48 million in 2004. This represents an increase of about 171% over that time frame. Near-term activities, involving industry partnerships for commercial demonstration of waste-to-ethanol technologies absorb up to and over 60% of the budget for each of the years of the plan.

Table 8-1. Budget Projections for the Ethanol Program

	FY 1998	FY 1999R		FY 2000		FY 2001	FY 2002	FY 2003	FY 2004
			80%	100%	130%				
Wastes-to-Ethanol	18526	26391	21013	26391	29958	26500	26500	26500	27000
Bio-Energy Crops-to-Ethanol	2500	6000	4000	6000	12000	6000	6000	8000	10000
Core Ethanol Technology R&D	6900	10000	8000	10000	12000	10000	10000	10000	11000
Total	**27926**	**42391**	**33013**	**42391**	**53958**	**42500**	**42600**	**44500**	**48000**

8.3 Benefits Associated with Biomass Ethanol for 100% Budget Level

Expected benefits associated with bio-ethanol for the 100% budget case are shown in Table 8-2. The biomass ethanol market grows from 600 million gallons in 2005 to 11 billion gallons by 2020. The biomass ethanol production cost will be reduced from $1.13 per gallon in 2000 to $0.72 per gallon in 2010, and a further reduction to $0.60 per gallon is achieved in 2020. The equivalent amount of oil displaced increases from 0.026 MM bpd in 2005 to 0.48 MM bpd in 2020. This corresponds to oil savings increasing from 46 trillion BTUs in 2005 to 849 trillion BTUs in 2020. Oil cost savings increase from $190 million in 2005 to $3.5 billion in 2020. The resulting carbon equivalent reductions increase from 0.96 million metric tons in 2005 to 17.60 million metric tons in 2020.

Figure 8-2. Budget Projections for the Ethanol Program R&D Activities at 100% Funding Level

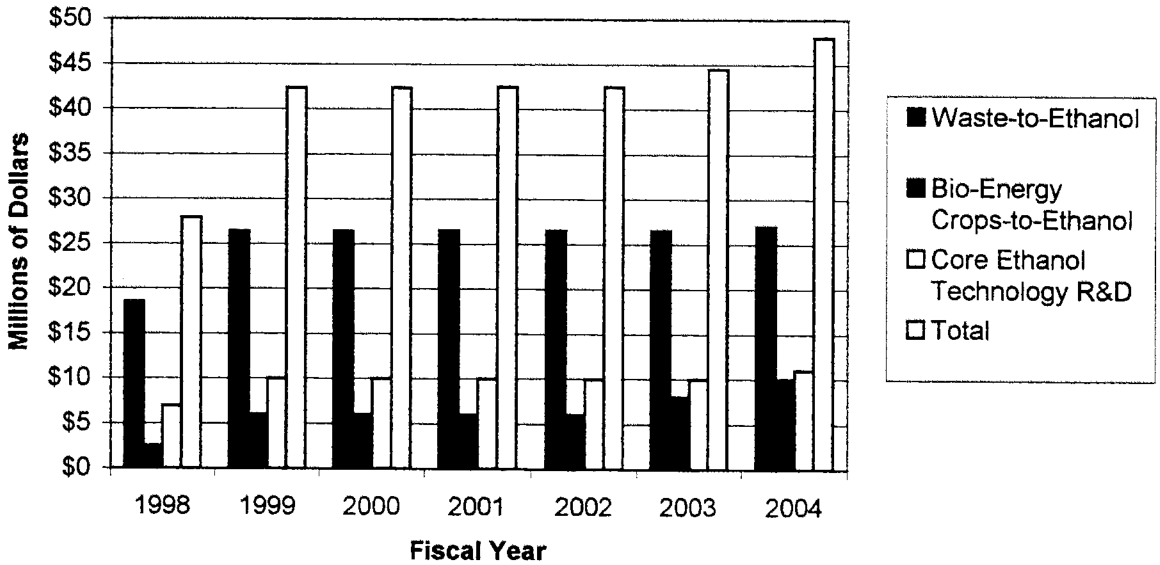


Table 8-2. Benefits Associated with Biomass Ethanol for 100% Budget Level

	2000	2005	2010	2015	2020
Million gallons bioethanol per year	0	600	4000	8500	11000
Target production cost per gallon	1.13	0.85	0.72	0.66	0.6
Carbon equivalent reduction (MM MT)	0	0.96	6.4	13.6	17.6
Oil displacement (MM bpd)	0	0.026	0.17	0.37	0.48
Oil Savings (trillion BTUs)	0	46	300	654	849
Oil Cost Savings (million $)	0.00	190.00	1241.00	2701.00	3504.00

In view of the perceived market risks associated with new technologies, the reduced budget would result in fewer demonstration partnerships and the benefits would be delayed by 3 to 4 years. At higher budget level, the benefits will be achieved 1 to 2 years ahead of schedule as a result of accelerated demonstration projects with industry partners.